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REPORT

OF THE

STATE BOARD OF GEOLOGICAL SURVEY

OF MICHIGAN

FOR THE YEAR 1903

BEING THE REPORT OF

ALFRED C. LANE

STATE GEOLOGIST.

BY AUTHORITY.

1905.
ROBERT SMITH PRINTING CO., LANSING, MICH.
STATE PRINTERS.

BOARD OF GEOLOGICAL SURVEY

1903

EX OFFICIO:

THE GOVERNOR OF THE STATE,

HON. A. T. BLISS, *President.*

THE SUPERINTENDENT OF PUBLIC INSTRUCTION,

HON. DELOS FALL, *Secretary.*

THE PRESIDENT OF THE STATE BOARD OF EDUCATION,

HON. L. L. WRIGHT.

137194

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ERRATA.

Page 38, line 13 from top, G. K., not C. K. Gilbert.

Page 5, line 2 from top, C. A., not A. C. Davis.

Page 25, foot note 3, the reference should be to "recherches sur le rôle physiologique," etc.

Page 37, line 1 at bottom, Pt., not Pl.

Page 74, line 21 from top, 534 feet, not 634 feet.

Page 106, after Na, line 13, insert NO_3:

Page 208, figure 8 should be figure 9.

FIFTH ANNUAL REPORT

OF THE

STATE GEOLOGIST

ALFRED C. LANE

TO THE

BOARD OF GEOLOGICAL SURVEY

FOR THE YEAR 1903.

LETTER OF TRANSMITTAL.

OFFICE OF THE STATE GEOLOGICAL SURVEY,
LANSING, MICHIGAN.

To the Honorable the Board of Geological Survey of the State of Michigan:

HON. A. T. BLISS, *President.*
HON. L. L. WRIGHT.
HON. DELOS FALL, *Secretary.*

Gentlemen—In accordance with the precedent two years ago, I make my report somewhat fuller in the year in which there is no legislative work and include therein, beside the mere account of what has been done, spent, and published, an account of current scientific results which are of interest and not soon likely to find final shape in any other way.

I will, as last year, begin with an account of the state of the areal work, and follow with the discussion of various subjects.

TUSCOLA COUNTY.

Prof. A. C. Davis has completed his contour map of Tuscola county and the engraver is at work upon it. It may possibly be ready to include in this report.

SAGINAW COUNTY.

I have collected further material upon Saginaw county, where borings have greatly multiplied. The United States Department of Agriculture is proposing to undertake a soil map in Saginaw and Bay counties[1] as well as Oakland, for which we have furnished maps, which will be of interest. I do not want to publish a county report on Saginaw county, however, until I can feel that it is reasonably final. There is some reason to believe that the anticlinal which, as I have said, probably passes through Saginaw runs nearly north and south toward Kawkawlin, as is later mentioned in connection with oil and gas prospects generally.

BAY COUNTY.

Mr. W. F. Cooper has prepared his maps of Bay county. Two of them are given herewith as Plate 1. The one is a contour map showing the elevations above sea level. Saginaw bay is about 580 feet above sea level, so that the elevations above the bay may readily be obtained by subtracting this number. Upon this map we have printed in blue a map showing the area of flowing wells of fresh water. Probably a very much larger area would yield flowing wells, but they would have to be deeper and more or less salt. This also shows the shrinkage of these areas.

ARENAC COUNTY.

Mr. W. M. Gregory has continued his work upon this region, and a map and report embodying much of this work is printed in connection with the report on gypsum, Part 2 of Volume IX of our reports.

[1] Letter, Milton Whitney.

WASHTENAW COUNTY—ANN ARBOR FOLIO.

The joint topographic survey of the Ann Arbor sheet by this Survey and the United States Survey, which was referred to in the annual report for 1901, has been completed. The edition of the resulting map by the United States Geological Survey is out before this report. But it has seemed to me wise to issue, as there was a demand for it as a base map for University studies, as Plate II. It is a photolithograph of their original sheet on a larger scale. It also shows (what their map will not show) the area left in wood lot in a county which has now for some time been settled. Elevations were painted frequently on trees and bridges and a number of the more important bench marks are herewith given.

Above tide.

713.507—Ypsilanti, Mich. Corner of North and River Sts., on top of hydrant.

797.043—Ypsilanti. Corner of Summit and Cross Sts., in stand pipe north side; bronze tablet.

881.857—Ann Arbor. University library, in south wall of; bronze tablet.

874.962—Ann Arbor. University Mechanic's Bldg., in masonry 8 feet north of south door and 3 feet below first floor.

842.797—Ann Arbor. Court house, in southeast corner of; bronze tablet.

838.408—Ann Arbor. At northwest corner of Huron and Fourth Sts.; city engineer's bench.

908.551—Whitmore Lake. Near center of S. W. ¼ of Sec. 5, opposite brick hardware store, on root of large oak tree.

819.016—Dixboro. In front of brick school house; iron post. P. B. M.

824.608—Saline. Saline bank; bronze tablet in corner stone.

620.140—New Boston. Highway bridge over Huron river; northeast pier of, on top of rivet.

602.633—Trenton. Corner of Washington and Pine Sts.; on top of hydrant.

587.214—Gibraltar. Edward Hall's residence. U. S. Coast and Geodetic Survey bench.

602.263—Flatrock. In front of Dr. Turner's residence; on root of large maple.

694.650—Milan. West of R. R. station, on north side of road, on root of hickory tree.

863.279—Dexter. M. C. R. R. stone arch, northeast corner of, on top of cap stone.

873.818—Hudson Mills. At cross roads; iron post. P. B. M.

882.925—Dover. At junction of roads, on boulder at west end of culvert.

735.7—Crossroads. Ridgeway.

699.3—Crossroads. Britton.

700.5—Wabash R. R. Britton.

702.5—D. T. & M. R. R. Britton.

700.2—Cone. Wabash crossing.

702.0—Milan. Center of.

Above tide.

691.9—Milan. Bridge.
721.0—York. Center of.
638.2—Maybee. Crossroads at station.

The geodetic or astronomical position of a number of points will also be found tabulated in Bulletins 201, p. 73, and 216, p. 213, of the United States Geological Survey, to be obtained gratis from the Director at Washington. One great advantage of the completion of this quadrangle is that the United States Survey have now engaged Prof. I. C. Russell of the University and Mr. Frank Leverett to prepare a geological map and description of the folio, which will serve as a model and be a great stimulus and aid to students both at the University and at the State Normal College.

THE FOREST RESERVE AREA.

In order to do what the Board could within the sphere of their work as at present defined to aid intelligent progress in solving the question of keeping up the lumber supply which has been so vital to Michigan in the past, Dr. Burton E. Livingston, of the University of Chicago, a native of Grand Rapids, who prepared for the 1901 report an interesting paper on the soil and plant relations of Kent county,[1] was employed to make a similar study of the soil and forest relations of a proposed forest reserve, as shown on the map given herewith, which accompanies his report.

[1]Discussed and some slight corrections made in Science, Aug. 14th, and Oct. 2, 1903.

Geological Survey of Michigan.

Annual Report for 1903. Plate II.

Wooded Areas of the Ann Arbor Quadrangle (in green).

[redacted]

[redacted]

[redacted]

THE RELATION OF SOILS TO NATURAL VEGETATION

IN ROSCOMMON AND CRAWFORD COUNTIES, MICHIGAN.

BY BURTON EDWARD LIVINGSTON.

INTRODUCTION.

That there is a marked relation between the natural vegetation of the State and the nature of the soils has long been known, at least in a general way. To determine exactly what this relation may be, both quantitatively and qualitatively, is, of course, a problem which it will take a long time to solve. A beginning can best be made by a careful study of small areas, and such a beginning was made in 1900 and 1901 by the present author in his study of the distribution of soils and vegetation in Kent county.[1] The investigations reported in the present paper were made in the summer of 1902, the area chosen being those townships of Roscommon and Crawford counties which embrace the lands set aside by the Legislature of 1901 as the Michigan Forestry Reserve, together with portions of certain adjacent townships. The work was carried on under the auspices of the Bureau of Forestry of the United States Department of Agriculture, in conjunction with the Board of Geological Survey of Michigan. A very brief report of the general conditions within the Reserve has already been published by the Michigan Forestry Commission.[2]

The method of attacking the problem was to plot upon a map the nature and extent of the various soil areas, and to do the same with the different types of vegetation. These types are known to botanists as *plant societies, formations,* or *associations,* and these are the units used in the study of vegetational distribution.[3] To determine the vegetational types, lists were made of the predominant plants in the different areas, and in the following discussion the types will be characterized by brief lists of the more important forms. Having once marked upon the map these two sets of data—of soil and of vegetation—the relation between the distribution of the two can be quite readily studied. Of course, this study goes hand in hand with the mapping and is not entirely a later deduction.

The accompanying map (Plate III) shows all of Roscommon county and the southern half of Crawford county. Careful study was made of

[1] Livingston, B. E., The distribution of the plant societies of Kent county, Michigan; Ann. Report Mich. State Board Geol. Survey, 1901, pp. 81-103. Idem, The distribution of the upland plant societies of Kent county, Michigan, Bot. Gaz. 35, 36-54, 1903.

[2] Livingston, B. E., The soils and vegetational possibilities of the Michigan Forestry Reserve. Report Mich. Forestry Commission, 1902, pp. 38-40.

[3] For some remarks upon this method of study the reader is referred to the paper on Kent county, loc. cit.

Townships 21, 22, 23, 24, and 25 N., Ranges 2, 3, and 4 W.; of Township 26 N., Ranges 3 and 4 W., and of parts of Townships 22 and 23 N., Range 1 W. The total area studied embraces about 600 square miles.

TOPOGRAPHY.[1]

The region consists of a series of ridges and depressions. The former are sometimes several miles wide, but more often narrow; they are always comparatively low, seldom rising more than 150 to 200 feet above the level of Higgins and Houghton lakes, which lie in the center of the Reserve. These ridges are terminal moraines, left by the ice sheet as it melted back at the close of the last glacial epoch. Between them are lower and more level stretches consisting, for the most part, of plains which gently slope downward from the ridge margin to the nearest stream. These were produced by the outwash of materials from the ice margin at the time the moraines were being formed, and their surface has been more or less eroded by water action since that time. Owing to the fact that they were formed by water action, the material of these plains is quite thoroughly freed from finer particles, and thus consists largely of sand. Gravel deposits are very rare throughout the region, and in the true sand plains it is seldom that one finds even good sized pebbles. It appears that the water from which the material was deposited was not moving swiftly enough to transport the gravel, but carried sand and clay. The finer particles, clay and loam, were carried away in the streams, but the sand remained in its present position.

The ridges, on the other hand, are more heterogeneous in composition. They were not so thoroughly washed by water while they were being piled up, and hence contain considerable quantities of finer particles, clay and loam, and of coarser ones, gravel. Sand is the predominating substance in their composition, however. They are usually bordered by rolling slopes of loamy sand which descend gently to the sand plains. A few of the ridges contain clay enough to make this soil best described by the term clay loam, or even loamy clay.

The whole country is underlain by clay, but this is generally far from the surface, sometimes 100 feet or more. Some of the depressions have clay surface soil. They were probably under cover of the ice sheet at the time of formation of the neighboring moraines and sand plains, or were the bottoms of glacial lakes.

The lowest portions of the depressions, whether these have sand or clay as surface soil, are almost always occupied by swamps or lakes. Through the swamps the very lowest part is often marked by a meandering stream channel, the line of drainage for all the region which lies between the neighboring ridges.

To understand more accurately the mutual relation of these ridges and depressions, the reader is referred to the map (Plate III). Ridge or moraine margins are there denoted in black by a hachured line, the hach-

[1] For much valuable aid in interpreting the glacial topography, I am indebted to Mr. Frank Leverett, of the U. S. Geological Survey, in whose company it was my pleasure to make a hasty survey of a large part of this region.

ures extending toward the depression. Swamp and channel margins as well as the limits of soil areas are marked by full red lines. Rulings in red denote the nature of the soil, as described in the map legend, swamps and stream channels are not ruled. Following is a description of the topography of the region.

From near the center of T. 26 N., R. 3 W., a ridge of gravelly and loamy sand about a mile in width extends eastward and a little southward across T. 26 N., R. 2 W. North of this moraine a gently sloping sand plain extends to the channel of the main stream of the Au Sable, a mile or more distant. Southward there is first a narrow strip of sand—apparently an old glacial channel—and beyond this a somewhat rolling stretch of gravelly and loamy sand rises to a second ridge, very similar to the first, which lies, approximately, in an east and west direction across the southern part of T. 26 N., R. 3 W. The two sand plains connect around the western end of the first named ridge, from which point an embayment of the plain extends southwest for a mile to the southeast corner of Sec. 20 of this township, cutting into the plateau-like rolling plain which borders the second ridge. The northern and western boundary of the lower plain is the channel of the Au Sable, and the swamp which surrounds the marl lake southeast of Grayling village.

From the vicinity of the last named lake the plain extends nearly two miles southwest into T. 26 N., R. 4 W., and is here surrounded by loamy rolling land. From the valley of the small creek which enters the Au Sable near the township line, westward to Portage lake, is a strip of swamp land varying from a half mile to two miles in width, and this is continued west of the lake in the broad swamp through which the Manistee river makes its beginning. The fact that the two river valleys are joined here in this manner made portage possible in the old days, and gave a name to the lake which lies in the line of connection. North of this portage swamp and of the lake, sandy plains extend to the upper Au Sable channel and to the northern limit of our area, except in the northwestern part, where rises the end of another gravelly and loamy morainic ridge. Between the main stream and its north branch lies a block of rather high, slightly rolling, loamy sand, on the northern edge of which is situated the town of Grayling.

In the south central portion of T. 26 N., R. 4 W., lies another ridge of hills, of gravelly and loamy sand, about three miles in length by two in width. North and northeast from this hilly area rolling loamy plains extend to Portage lake and the swamp already described, and to the lobe of sandy land projecting southwestward from the Au Sable channel.

Directly south of the last named moraine is another ridge of somewhat smaller size. Westward and southward it slopes through a rolling loamy plain to a plain of almost pure sand, about half a mile away.

Northward this rolling plain joins the two ridges at their western ends, but between their eastern portions is an area of somewhat clayey loam which extends eastward about three and one-half miles, broadening beyond the ridges until it is nearly three miles wide from north to south. The latter area is level. To the east it joins the hilly clay loam of a long, narrow ridge which extends across T. 25 N., R. 3 W., and almost across T. 25 N., R. 2 W. The last named ridge slopes northward through loamy sand to the sand plain which separates it from the second ridge described. Southward it slopes in the same manner to the most extensive sand plain

of our area. This plain extends from north and east of Cheney, southward through the last mentioned ridge by a very narrow valley directly south of the village, thence westward along the northern margin of the Beaver creek swamp to the limits of our map, thence northward to end about a mile south of the Manistee river swamp. East of Cheney it borders the northern edge of the ridge, excepting where its margin bends northward to give place to a small low area of clay which lies just north of the center of T. 25 N., R. 2 W. This area of clay is quite unique in this portion of the region. Southeast of Cheney the gravelly and loamy material of the ridge extends to the channel of the south branch of the Au Sable.

Southward from the Beaver creek swamp the land rises gradually to another ridge of gravelly and loamy sand, which extends along the north shore of Higgins lake and bends southward to end in the southwestern part of T. 24 N., R. 2 W. This ridge is broken through by a sand-bordered swamp a mile north of the center of the western boundary of the last named township. Southward from the east-and-west portion of this ridge, rolling loamy sand extends to the Houghton lake swamp, to Higgins lake, and to the swamp of The Cut, the latter being the outlet of the lake. I am informed by residents that The Cut suffered much deepening and widening some twenty years ago by the driving of logs through it. This very probably lowered the level of Higgins lake several feet, as the well-marked sand beaches of the latter would seem to indicate. Near its beginning the stream passes through a small area of low clay, the northernmost of the group of semi-swamp clays in the vicinity of Houghton lake.

The triangle of dry land lying between the South Branch and its tributary, Robinson creek, is nearly all a sand plain. Near the streams it is loamy and in its southern part rises a small ridge of gravelly and loamy sand. South of the ridge a mile or more of swamp extends to the abrupt mass of hilly land known as the Murray hills, in the northern part of T. 25 N., R. 2 W. These are of sandy clay, rather heavy and excellent for cultivation. South of the Murray hills lie the Jackson hills of gravelly and loamy sand, the two being joined by a plain of loamy sand, and forming together a great island entirely surrounded by swamp. Northwest of the latter ridge is another similar one (T. 23 N., R. 2 and 3 W.), also an island, but surrounded by a band of low clay. Another ridge, of the gravelly type, about one mile in width, follows closely the southern shore of Higgins lake. Southward from the latter moraine, loamy sand extends to the margin of the great Houghton lake swamp and to that of The Cut. A great swamp complex extends from the Muskegon river along the northern shore of Houghton lake, and continues in an easterly direction, southward of the Jackson hills already mentioned, to connect with the swamp of St. Helen's lake. On the west it also extends far to the south, connecting with the maze of swampy stretches which form the valleys of Bear, Wolf, Town Line, Knappen, and Denton creeks. North of Houghton lake are a number of irregular low islands, some of clay loam, some of clay, and some of loamy sand. These are shown on the map and need not be described in detail. West of the lake is a large low clay mass in the southwest portion of T. 23 N., R. 4 W.

South of Houghton lake lies another ridge termed Norway hill, extending from Sec. 3 of T. 22 N., R. 4 W., to Sec. 33 of T. 22 N., R. 3 W. Excepting in its northwestern part, it is surrounded by loamy sand plains, which

slope to sandy bottomed swamps on the southwest, south, and northeast. These swamps, in the valleys of Town Line creek, Wolf creek and Bear creek, are cut up in an irregular and fantastic way by dry ridges of loamy sand. The same is true of the swamps lying southeast of Houghton lake, about Denton and Knappen creeks. The highest part of Norway hill contains a considerable amount of clay on or near the surface. About a mile and a half from its northwestern extremity, this ridge is broken through by a clay plain about half a mile in width. This plain bends sharply to the northwest on either side of the ridge, and continues in the direction beyond the end of the latter. West and southwest of Houghton lake are also patches of drained land, and much of the swamp itself has a clay bottom not far beneath the surface.

St. Helens lake (T. 23 N., R. 1 W.) is nearly surrounded by swamp land. East of it is a sand plain which abuts upon the lake at the site of the abandoned lumber town, with its lonely railroad station and school house fast going to ruin. Here, too, at the time of this study, was a small saw mill, cutting into lumber what was still good of the many "deadhead" logs lifted from the lake bottom. This whole region is being improved by a Chicago company and I was told that much of the swampy region will soon be artificially drained. South of the lake a plain of loamy sand rises to a small ridge of the gravelly type, and still farther south to the great hilly area which cuts across the southeastern part of our region. The latter is the northern edge of a broad terminal moraine which can be traced across several counties. It is of loamy soil, partly of the sandy type, but for the most part containing considerable quantities of clay. Northwestward it slopes downward to irregular areas of loamy sand and clay which reach out into the great swamp maze already mentioned.

SOILS.

The soils are nearly all sandy. The only exceptions to this statement are the few low clay areas mentioned in the preceding paragraphs, together with the Murray hills, parts of Norway hill, and portions of the great southern ridge in T. 21 N., R. 1 and 2 W., which are the only ridges which can truly be called clayey. The surface soil of these ridges contains considerable quantities of sand, however. The other ridges are of gravelly and loamy sand, that is their surface soil is mostly of sand, but with a sufficient admixture of fine particles to produce a marked difference in physical properties from that of the true sand plains, while they also contain pebbles and sometimes scattered boulders. The slopes downward from these ridges are of sand, either pure or loamy. They seldom contain many pebbles of any considerable size, thus being more thoroughly washed by water than are the ridges. The true sand plains contain little or no loamy material and no pebbles. They are of a fine, grayish white sand, which drifts readily by the wind when loosened. I have seen the surface soil actually blown away and piled in miniature dunes along the wire fences, in places where the worst of the sandy soils had been attacked for cultivation.

Obviously, difference in degree of water-washing, and hence of sorting

of particles, determines these different soil characters. Sandy soils are composed of coarse particles and contain much silica, loamy soils are of finer particles and contain considerable quantities of alumina, while clay soils are of still more finely divided materials and contain a much larger percentage of alumina. Since all of this material was transported to its present position by glacial action, and since it must have been quite thoroughly mixed by this agency, it is reasonable to suppose that, had it not been water washed during and after its deposit, it would be at least fairly uniform in its mineral constituents. The washing process sorted the soils accordingly to size of particles, but also according to their chemical nature. This is partly due to the fact that alumina breaks down into fine particles more readily than does silica. It is also due to the fact that, in well-washed soils, even the less soluble constituents are apt to be actually dissolved and washed out to a greater or less degree. Thus, phosphates and sulphates are usually less abundant in well-washed soils than in those less thoroughly washed.

In this glaciated region, fine soils, such as clay, were either deposited under the ice of the glacial epoch, and hence not well washed, or else they were deposited from deep and very slowly flowing water. The former variety therefore usually contains many coarser particles, as loam, sand, and pebbles. In the case of loamy soils, a good part of the fine material has been washed out, but a considerable amount remains with the sand, so as to give it a loamy character. Since the washing here was not thorough, pebbles are often found amongst the sand and loam. This is especially so of the ridges. The water which flowed over such soils at the time of their formation must have been moving with a velocity such that it deposited or left unmoved sand and gravel together with some finer material caught between the coarser particles, but carried away most of the latter. Sandy soils are still more thoroughly washed; the gravel was left farther up stream, usually on the slopes of the ridges, while the clay was held in suspension, to be deposited at a lower level, where the velocity decreased.

On account of the difference in size of particles which results from water washing, there naturally follows a corresponding difference in the size of the interstitial spaces of the soil; the finer the component particles, the smaller must be the spaces between them. And, because of this, there comes to be a corresponding difference in water holding power and water lifting power. The surface tension of water films is greater, and hence more effective, over small surfaces than over large ones, and film surfaces are greater in coarse than in fine soil. Thus, the smaller the particles of any soil, the more water it can hold and the higher it can lift this liquid from a lower level. Warming[1] quotes Wollny as having shown that quartz sand consisting of grains over 1 to 2 mm. in diameter can hold only one-tenth as much water as that with grains 0.01 to 0.07 mm. in diameter. Schimper[2] states that loose sand has a water capacity of 13.7% of its volume, while clay exhibits this property to the extent of 40.9%.

The nature of the soil particles themselves often plays an important part in determining the water-retaining and water-lifting power.

[1] Warming, E., Lehrbuch der ökologischen Pflanzengeographie, übersetzt von Dr. E. Knoblauch. Bearbeitet von P. Graebner. Berlin, 1902, p. 55.
[2] Schimper, A. F. W., Pflanzengeographie auf physiologischer Grundlage. Jena, 1898, p. 94.

Especially is this so in the case of humus, which is composed of organic debris, decayed plant parts and, to some extent, of animal offal. Pure humus has a great power to hold and lift water. This is partly because of its very fine particles, but is also to be traced in part to the actual penetration (by imbibition) of the liquid into the intermolecular spaces of the organic substance itself. Thus, by admixture of humus to a coarse (and therefore porous and permeable) soil, the water-retaining power of such a soil is increased.

The filtering power, or permeability to water, of a soil increases, of course, with decrease in its capillary power. Also, its permeability to air increases in the same way.

A general exposition of this question of size of particles, water-retaining power, etc. is to be found in either of the two works just cited. A much better treatment, however, has appeared in the publications of Briggs[1] and Whitney.[2] The reader is referred especially to the writings of the former author.

TABLE I.—SHOWING RESULTS OF ANALYSES OF SOILS OF NORTHERN MICHIGAN.

COMPILED FROM TABLES BY R. C. KEDZIE.

	Location.	Tittabawassee valley.	Mecosta county.	Gaylord.	Missaukee county.	Lake county.	Averages, six samples Crawford and Oscoda counties.
Physical description.	Nature of soil.....	Clay.	Loam.	Loam.	Loam.	Sand.	Sand.
	Water capacity..	51.40	45.40	39.60	39.10	35.30	33.00
	Forest type	Hardwood.	White pine	Hardwood.	Hardwood.	Jack pine.	Jack pine.
Chemical description.	Silica.....	67.20	75.54	91.92	69.89	92.48	94.22
	Alumina....	6.31	10.62	2.93	8.35	2.22	.....
	Fe.....	7.91	3.80	0.90	5.60	1.59	1.88
	Ca.....	1.64	0.94	0.40	1.15	0.35	0.37
	Mg.....	1.23	0.48	0.13	0.98	0.30	0.06
	K..... ...	1.85	1.96	0.61	1.95	0.73	0.85
	Na.....	1.15	1.25	0.28	1.15	0.32	0.27
	H_2SO_4.....	0.30	0.26	0.10	0.25	0.06	0.01
	H_3PO_4.....	0.49	0.44	0.14	0.28	0.14	0.08
	Nitrogen...	0.22	0.12	0.07	0.11	0.04	.....
	Organic matter....	7.48	2.97	2.20	4.73	1.22	2.16

[1] Briggs, L. J., The mechanics of soil moisture. U. S. Dept. of Agric., Div. of Soils, Bull. 10, 1897. Investigations on the physical properties of soils, U. S. Dept. of Agric., Field Operations of the Div. of Soils, 1900, 1901, p 415-421.

[2] Whitney. M., The Division of Soils, Year book U. S. Dept. of Agric. 1897, pp. 120-135. Soil Moisture. U. S. Dept. of Agric., Div. of Soils, Bull. 9, 1897.

TABLE II.—RESULTS OF ANALYSES OF JACK PINE SAND NEAR GRAYLING.

COMPILED FROM TABLES BY R. C. KEDZIE.

Condition of soil.		Virgin soil.	Cultivated and green-manured for 3 years.	
			Spurry, vetch and peas plowed under.	Spurry, vetch and red clover plowed under.
Chemical description.	Silica	94.97	94.30	95.02
	Alumina	1.08	0.61	0.49
	Fe	0.86	1.17	0.78
	Ca	0.20	0 24	0.32
	Mg	0.12	0.17	0.15
	K	0.20	0.33	0.30
	Na	0.90	0 58	0.62
	H_2SO_4	0.06	0.05	0.05
	H_3PO_4	0.05	0.04	0.01
	Nitrogen	0.02	0.05	0.04
	Organic matter	1.61	2.50	2.35

Chemical analyses of a number of Michigan soils have been made and published by Kedzie.[1] Tables I and II, showing chemical constituents and water capacity, are compiled from his pages. The samples described are all from the portion of the State in which lies the Forestry Reserve. The amount of the different chemicals found in the soils are stated in per cent. of total air-dry weight, excepting in the case of water capacity, which is dry soil volume, and is thus comparable to our retaining power,—although this is not stated in the original papers.

It will be noticed in the tables that sandy soils usually exhibit a marked scarcity of soluble salts. This fact may be explained in part by the "leaching" action of the percolating waters as well as by the thorough washing to which these soils were subjected at the time of their deposition. The water of precipitation percolates rapidly through these porous soils and may often wash the soluble salts down toward the level of the ground water, a process which is termed "leaching."[2]

In humus soils, it is probably not to the point to determine humus content and water capacity after the humus has been mixed with the lower layers; the effect of the organic substance is very much more marked when the humus lies as a distinct layer on the surface than when it is distributed through the underlying soil. The humus layer acts like a sponge filled with water, and allows the water to pass slowly down

[1] Kedzie, R. C., The jack pine plains, Mich. Agric. Exp. Sta. Bull. 87. Also 27th Ann. Rpt. Secy. State Bd. Agric. 1888, pp. 207-210.
Idem, The Soils of Michigan, Mich. Agric. Exp. Sta., Bull. 91. Also, 32d Ann. Rept. Secy. State Bd. Agric. 1894, pp. 403-415.

[2] Whether leaching occurs in such soils to a greater extent than the opposite process (i. e. the lifting of soluble salts to the surface layers by evaporation), is an open question. Alkali spots seem far from rare even in humid regions. The whole question seems to need investigation. See Cameron, F. K., Soil solutions, etc., Bull. 17, Div. of Soils, U. S. Dep't. of Agric., pp. 36-39, 1901. Also Means, Thos. H., On the reason for the retention of salts near the surface of soils. Science N. S. 15:33-35, 1902, and some discussion of the same by Hilgard, E. W., The rise of alkali salts to the soil surface, ibid 314-315, 1902.

into the underlying layers, and thus keep them moist much longer than they would otherwise be. The samples described above were probably taken from surface soil, perhaps reaching a depth of eight to ten inches; nothing is said regarding this question in the reports from which these data were derived.

Table III represents the water capacity of several soil samples collected by the author in Roscommon and Crawford counties. The determinations were made in the Hull Botanical Laboratory of The University of Chicago. In this table water capacity denotes the amount of water which the soil is capable of holding, measured in per cent. of total *volume* of dry soil. This is the only way to secure data which can be used in comparing this property in different soils, as has been pointed out by Whitney.

TABLE III—SHOWING WATER CAPACITY OF ROSCOMMON AND CRAWFORD SOILS.

Sample, No.	Township.	Soil.	Topography type.	Forest type.	Water capacity, volume per cent.	
					Subsoil.	Surface.
1.....	21, 4	Clay loam....	Plain.....	Hardwood....	43.5	(Humus) 74.1
2.....	22, 4	Grav. loam...	Ridge.....	Norway.....	45.9	" 40 0
3.....	25, 4	Sand.....	Plain.....	Jack.....	37.0	" 38.0
4.....	22, 4	Loamy sand..	Plain.....	Norway.....	43.5	Like subsoil.
5.....	22, 4	Clay.....	Plain.....	Hardwood....	56 9	Mainly humus (?0. + ?)

It is noticeable that the sub-soil of sample 1 has the same water capacity as that of the sample 4, but the surface humus of the former brings the total water-retaining power up to a point far above that of the latter. The surface of sample 4 was apparently like the subsoil, it contained very little humus.

The discussion of the relation of the nature of the soil to that of the vegetation will be reserved until the types of vegetation have been described.

THE TYPES OF VEGETATION.

The vegetation of the region may be sub-divided into several types or plant societies. These grade more or less into one another, but there are few places where an observer would be puzzled to determine what particular type he was in. There are to be distinguished, four types on the uplands and three on the lowlands. These will be described in the following paragraphs.

I. THE TYPES CHARACTERIZED.

Practically all the area under discussion has been lumbered. A virgin pine forest is almost entirely unknown now, though some of the finest

pine of the State was cut here. What hardwood areas there are have been left almost untouched until recently, except for the removal of the white pine originally scattered through them. But the hardwood, too, is now being rapidly removed, and it will not be long before there will be none left. In the lowlands, the merchantable arbor-vitae or white cedar has very largely been removed, as has also much of the spruce and even considerable quantities of tamarack. In the present description, will be presented first a characterization of the original vegetational cover, as well as this can be determined at the present time. Then will follow a description of the present conditions. The types to be found here are as follows: 1. On the uplands,—A. the Hardwood Type, B. the White Pine Type, C. the Norway Pine Type, D. The Jack Pine Type; and on the lowlands,—E. the Open Meadow Type, F. the Tamarack-Arbor Vitæ Type, and G. The Mixed Type.

1. The Upland Types.

A. The Hardwood Type.—There is very little hardwood in the region studied, but what there is is typical of all northern Michigan. Areas so covered have not been so thoroughly lumbered as those covered with pine forests. The original form of this type comprised the following characteristic trees: sugar maple, beech, hemlock, red and American elm, balsam fir, yellow birch, some spruce, and scattered white pine, the latter of enormous size, together with such low forms as raspberry, squaw-berry, Lycopodium clavatum, yew, June-berry, Echinosperum virginicum, American pennyroyal, red-berried elder, Solidago caesia, etc. Maple, beech and hemlock made up three-fourths of the forest, sometimes one and sometimes another of the three being most numerous.

Lumbering has affected this type very little, excepting by the removal of the white pine and some of the hemlock. Hardwood lumbering is now going on in the areas covered by this type, in these operations everything is being removed which is merchantable. Fires have not injured this form of forest to any great extent, and the original humus usually remains.

B. The White Pine Type.—This is typical pinery, often containing little besides white pine. Usually, however, there is an admixture of Norway pine, and often of hardwoods. The type is quite sharply distinguished from the preceding, but not nearly so well marked off from the following type, into which it grades in many places.

As has been stated, there is at present hardly any of this type in the region under discussion. In lumbering, all the pine was removed and the subsequent fires have killed practically all the young growth of this tree as well as the scattering hardwoods. Over vast stretches originally covered with white pine there are now no trees at all. They are regions of dwarfed white and red oaks, red maple, and a number of shrubs. The oaks and maples are rarely more than twice as high as a man; they are burned down every few years, and exist here at all only because of the fact that they sprout from the roots which are seldom killed by the fires. These shrubby oaks and maples thus possess enormous roots which are partially dead or dying, gnarled and contorted and deformed by frequent burning. It is these which are called "grubs" by dwellers in the region. For an interesting description of how maples, oaks, etc., are able to attain to a great age in this manner, and still not be over a few feet in height,

the reader is referred to Beal's paper on this subject.[1] It is accompanied by excellent illustrations.

Among the lower forms occurring here may be mentioned the following:—Stag-horn sumach, Monarda fistulosa, brake, huckleberry (Gaylussacia resinosa), blueberry (Vaccinium pennsylvanium, canadense and vacillans), sweet fern, Solidago concolor, witch-hazel, etc. The ground between the blackened stumps is now thoroughly covered by densely growing sweet fern, huckleberry, and blueberry, the growth of the former of these being so luxurious that the numerous prostrate logs are often entirely hidden from sight, so that passage through these old "pine slashings" is rendered very difficult.

C. The Norway Pine Type.—At the time of lumbering, this type consisted mainly of the species for which it is named, but usually contained scattering white pine and more numerous, though often dwarfed, red and white oaks and red maples. The present aspect of this type is much the same as that of the preceding. The two oaks, red maple, and seedling Norway are the characteristic trees now. Seedling Norways are more numerous than in the preceding type, perhaps because of the greater number of seed trees here as well as the somewhat greater ability of this species to withstand fire than that possessed by the white pine. The low plants are much the same as in the last, Solidago caesia of that type is replaced here by S. juncea, and Liatris scariosa is common here, while in the other group it was of rare occurrence.

D. The Jack Pine Type.—This is the most open of the series and occurs in the most sterile sands of the area. The only trees are the jack pine, scarlet oak, choke cherry, and seedings of Populus tremuloides and P. grandidentata. All but the pine and oak are hardly more than shrubs. The pines occur in two forms, one with a tall trunk and a crown of short branches at the summit, the other with branches longer and extending nearly to the ground. The former is called by lumbermen "black jack pine," the second "yellow jack pine." The shape of the tree is of course caused by its place of growth, the former occurring in dense groups, the latter in the open.

Besides the trees, there occur as characteristic on the jack pine areas the following low plants:—Brake, Solidago nemoralis, the three blueberries above mentioned (but not huckleberry), bearberry, sweet fern, sand cherry, pin cherry, Andropogon scoparius and furcatus, Danthonia, Liatris cylindracea, dwarf willow, reindeer lichen, etc. This type comprises the worst part of what is called "the plains."

2. The Lowland Types.

For the most part, the swamps which were originally wooded have not been denuded of forest. Where they contained white pine, that was taken out, leaving the other trees, which protected the undergrowth and soon produced a dense, almost jungle like formation. Within the past few years the merchantable arbor-vitae and tamarack have been removed from these swamps, but there are almost always left enough small trees to produce shade. Also the swamps have not been subjected to burning nearly so often as the uplands, and are generally in much more nearly

[1] Beal, W. J., Observations on the succession of forests in northern Michigan, 27th annual report Bd. of Agric. Mich., 1888, pp. 74-78.

their original condition than are the latter. The three types may be described as follows:

E. The Open Meadow Type.—This is treeless or nearly so, partly open hay meadow, largely of "blue-joint," (Calamagrostis canadensis), partly of bulrush and cattail marsh, and partly of sphagnum bog. It grades into the other two types.

F. The Tamarack and Arbor-Vitae Swamp.—This is the typical swamp of the region. It contains tamarack, arbor-vitae or white cedar, black and white spruce, and balsam fir, which form dense and often impassable, thickets. In some localities the tamarack occupies almost all the ground to the exclusion of other trees, and in other places the same is true of the arbor-vitæ. But there is not nearly so much tendency here for these two trees to form separate and distinct types as is found farther south.[1] There the tamarack seems to occupy the portions of the swamp lands which are most poorly drained, the arbor-vitæ growing best in localities where drainage is more thorough, yet still not complete enough for the river swamp vegetation. Here the question of drainage does not appear to play so important a part.

G. The Mixed Swamp.—This formation is found near swamp margins, especially where the underlying clay is near the surface. Thus, it often occurs along lines where the hardwood forest reaches down toward the swamp. It may be looked upon as intermediate between the tamarack and arbor-vitæ type and that of the hardwood. There is always a great mingling of species here. Among the trees are: Tamarack, arbor-vitæ, the spruces, balsam fir, white and yellow birch (Betula papyrifera and lutea), black ash, hemlock, mountain ash, sugar maple, Prunus serotina, white pine, June-berry, etc., together with such low forms as raspberry, blackberry, brake, Lycopodium clavatum, yew, alder, and Ilex verticellata. The relative proportions of the different trees vary from one locality to another, and nothing definite can be stated in this regard.

II. THE DISTRIBUTION OF THE FOREST TYPES.

The actual distribution of the different vegetational types is shown by green lines on the accompanying map. (Plate III.) The upland types are denoted letters, each area bearing a letter to denote the type which it represents. Thus H, denotes hardwood, W, white pine, N, Norway pine, and J, jack pine. Thus these letters stand for types A, B, C, and D, respectively. Of the lowland formation the open meadow is represented by the conventional sign for marsh where it exists over broad areas. The extent of the areas occupied by the types F and G was not carefully enough worked out to be placed upon the map.

The main facts of distribution are presented in the following paragraphs. The upland and the lowland types will be considered separately.

1. The Uplands.

The Hardwood Type occurs in this region always in soils which contain considerable amounts of clay. Such soils are always covered to a depth of several inches with leafmold or humus, and in this layer the

[1] For a description of the conditions further south in the state, the reader is referred to the author's paper on Kent county, loc. cit.

seedlings of hardwood and hemlock grow and thrive. The white pine type occurs on the Murray hills, on the most clayey parts of Norway hill, and on the great northwestern moraine, in T. 21 N., R. 2 W. These soils are often as clayey as those of many of the hardwood areas, but are higher and therefore better drained. It also occupies most of the gravelly ridge in T. 25 N., R. 2 W. Very often the swamp margins are occupied by this type, especially where the slopes are not abrupt, a condition which gives humus a chance to collect in and upon the sand.

The Norway Pine Type occupies gravelly ridges and loamy sand plains. The soil here is somewhat better than in the locations held by the next type, but it is generally too poor for profitable general agriculture. As will be seen by a glance at the map, most of the uplands studied were originally covered by this type.

The Jack Pine Type occupies only the most thoroughly washed of the sand plains. Excepting in the northern two tiers of townships and in T. 24 N., R. 2 W. there is practically none of this type in the area. These localities lie in the valley of the Au Sable. The parts lying about the head waters of the Muskegon have abundant plains of loamy sand, but these support the type of Norway pine. This fact has no connection with the rivers themselves, however, for farther down the Muskegon are to be found typical jack pine barrens. The soil of this type is almost worthless for agriculture; it is light and dry, and where the surface is broken it is apt to be wind blown, and often forms small traveling dunes. This has been the fate of many once cultivated fields in the northern portion of the Beaver Creek valley and also still farther north in the neighborhood of Grayling.

2. The Lowlands.

As has been said, the distribution of the lowland types was not worked out with accuracy. Great difficulty was experienced in studying such areas, for the swamps are often almost utterly impassable. The greatest areas of open marsh encountered are marked on the map, as already described. There are doubtless many areas of like nature which were not seen at all, but these cannot be of very great extent. In the swamps the ground is covered with a layer of humus, usually of the nature of peat, and there seems to be no difference in this substance between the sand and the clay areas. Neither is there any apparent difference in the swamp vegetation whether it is upon sand or clay.

THE RELATIONS BETWEEN THE DISTRIBUTION OF FOREST TYPES AND THAT OF SOIL TYPES.

The nature of the types seem to be very closely dependent upon the nearness of the underground water level to the surface, and upon the nature of the soil. The former factor determines at once whether the vegetation shall be classified as upland or lowland. The distinction between these two classes is more evident at first sight than it is after closer study; it is difficult to state just how far the water level may recede from the surface and still support a lowland type of forest. Very few determinations have been made in this regard. Mayr[1] states for northern Wisconsin, that where the water level is less than one inch below the soil surface, the vegetation is of the swamp form, while if it is lower than one or two inches the soil bears white pine or some other upland type. This was on sandy soil. Warming[2] has determined the depth of water level in various soils in Denmark. He finds Juncus and Carex forms holding the ground until the water level is about 9 inches below the surface; with water at a depth of 12 to 15 inches, grasses grow well, forming what we should term a moist meadow. With the water from 18 to 24 inches below the surface all grains grow well; this seems to represent our fertile uplands. With the water still lower the soil becomes poor for grains. Data from natural vegetation have, as far as I know, not been gathered. My own observations are not accurate enough here to be of value.

The more water there is in the soil, the less is the access of air to the roots of the plants growing therein. This is because air diffuses much more slowly when in aqueous solution than in the form of a gas. Gas diffusion is checked by the filling of the interstices of the soil with water, and hence most of the oxygen which reaches roots in wet soil must do so by diffusing as a solute in the water. Since ordinary plants cannot grow without rather free access of oxygen to their roots, it follows that a soil saturated with water is very poorly adapted to their growth.[3] This is perhaps the reason why saturated soils are usually occupied by a vegetation of entirely different aspect from that found on soils which are dryer, thus we have swamp or lowland types of vegetation contrasted with those of the upland. Swamp plants are able to live with a scanty supply of air to their roots, but since uplands plants cannot, it is possible to have too much water in the soil for the well being of the latter. Thus, areas with much water are occupied by typical swamp plants, often probably, because they alone are able to live in this situation.

Besides this primary classification of the vegetation groups into those of upland and lowland, there is evidently another classification lying within each one of these two classes. Thus I have characterized four types of forest on the uplands and three on the lowlands. These types seem also to be dependent upon the nature of the soil, at least in the uplands. The considerations will now be taken up in detail.

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[1] Mayr, H., Die Waldungen von Nordamerika. Munich. 1890.
[2] Warming, E., Bot. Tid. 21, 1897. For a résumé of this paper I am indebted to one of my students Mr. G. H. Jensen.
[3] Wollny, E., U. S. Dept. of Agric. Exp. Sta. Record 4, pp. 528-543, 627-641, 1895. Compare also Plat, V in the Annual report for 1901.

1. *Factors Determining Distribution in the Uplands.*

(a) The Original Distribution.—Throughout the uplands excepting in the narrow swamp borders, and in the low clay plains about Houghton lake, the underground water level is far from the surface. The depth varies from 15 to 75 feet and even more.

Wherever the upland surface lies near the water level, its vegetation takes the form of one of two types, either the hardwood (on the low clay) or the white pine (on the low sand and loam). Farther above permanent water, the former of these types occurs only in one locality, in the northwestern part of the area, and there upon clay loam. Where the water level is not near the surface, the white pine type occurs only on clay and clay loam. The Norway type is found throughout the area on loamy or loamy and gravelly sand, and the jack pine type appears exclusively on sand which is hardly at all loamy, and thoroughly washed. Now and then there are found a few trees of jack pine (without, however, the other character trees of the type) in the loamy sand where the Norway predominates. I have seen some very small stretches of sandy land even on the great southeastern ridge, where jack pines were mingled with the stumps of the white pine and the small white and red oaks and red maples. But the purpose of the present classification is not to consider individual trees, but the complexes characterized by certain species. Thus, the occurrence of a few trees of a different type is not to be considered as invalidating the predominant type, especially since these are not accompanied by the other characterizing species.

The distribution of the upland types just described may be tabulated as follows:

TABLE IV.—RELATION OF WATER LEVEL TO VEGETATION TYPE.

	Position of Underground Water Level.	
Soil.	*Near Surface.*	*Deep.*
Sand	B, C	D
Sandy loam	B, C	C
Clay loam	A, B	B[1]
Clay	A, B	B

In the above table the different types are denoted by the letters already used in their description. It will be noticed that from clay to sand, with water level deeply seated, we have a series passing from the white pine type to that of the jack through the Norway. A single exception to this is the hardwood area on clay loam in T. 25 N., R. 4 W., to be spoken of in a later paragraph. But with the water level near the surface, the series runs from the hardwood of the Norway type, the jack pine not occurring at all. This observation seems to agree with those made by Mayr[2] in northern Wisconsin. He states that sand ridges rising out of a swamp usually bear white pine on the slope, then Norway, and, lastly the jack on the most elevated parts. The same author points out that white pine will grow well on poor sand if the water table is near the surface. This seems to be true here also.

[1] The hardwood in T. 25 N., R. 4 W.
[2] Mayr, H., loc. cit., p. 207.

To explain the distribution of the different types, either of two hypotheses may be resorted to. As has already been mentioned, the finer the particles of a soil, the greater its power to lift and hold water above the underground level. It is well known, too, that some soils contain more of certain salts than do others. Thus, the reason for the observed distribution on the uplands may be sought for either in the water-retaining power of the soil or in its chemical constituents.[1] That the depth of the water table itself sometimes plays an important part in determining plant distribution is shown by the above table. Along a swamp margin the increased amount of water may influence the plant growth directly. But how much of this observed influence is to be considered as indirect, is an open question. The presence of water alters a number of other soil factors. First, it checks free access of air. Thus, if jack pine roots need more air than those of Norway, this might explain why the former fails along swamp borders and the latter takes its place.

Secondly, with increase in water content, there follows a more equal distribution of the dissolved salts, for these can diffuse only through continuous water films, and the greater is the cross section of the latter, the more rapidly will diffusion take place. As a corollary to this statement, it follows that "leaching," the washing down of soluble salts out of the upper into the lower strata, cannot occur in a soil which is constantly filled with water. Moreover, in a moist or wet soil, if not in a dry one,[2] the upward diffusion of salts during dry times would probably more than counteract the downward washing during heavy rains. The upper layers of a wet soil are apt to have more soluble salts after they have lain for a time than when first placed. This is, of course, on account of the evaporation at the surface, which increases the concentration of the soil solutions in the upper layers.[3] Of course this indirect effect cannot be exhibited unless there is a sufficient amount of salts in the more deeply lying soil. But in a glacial region such as this there can be little doubt as to the presence of these salts relatively near the surface.

Thirdly, the checking of the air access, coincident with the filling of the pores of the soil with water, must check the process of oxidation and accelerate the formation of humus.

Fourthly, the growth of the micro-organisms of the soil, the soil bacteria, etc., takes place much more rapidly in a moist than in a dry soil; they need moisture for development. However, excess of water is also deleterious to the growth of many of these organisms, so that a soil may be too wet for them. But flooding is not so fatal in sand as in finer soils.[4] It is well known that soil bacteria and micorhizal forms are very important in increasing the amount of nitrates in the soil, and thus it appears that a moist soil, even a wet soil if it be sandy, will gain nitrates much more rapidly than a dry one.

Fifthly, the curve of temperature changes in a moist soil is much flatter (i. e., the changes are less marked) in a moist than in a dry soil.

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[1] For early papers on this subject see:
Thurmann, J., Essai de phytostatique appliquee á la chaine du Jura, Berne. 1849.
Nägeli, C., Sitzungsber. Akad. Wiss. München. 1865.
Unger, Ueber den Einfluss des Bodens auf die Vertellung der Gewächse. Wien. 1836.
A more recent paper dealing with this question of soil physics and soil chemistry as influencing vegetation is the following: Cowles, H. C., Bull. Amer. Bureau of Geog. 2: 1-26. 1901.

[2] See footnote, p. 16.

[3] Dr. Cameron of the U. S. Bureau of Soil, tells me that most soils have more soluble salts near the surface than in deeper layers.

[4] Gain, E., Action de l'eau du sol sur la végétation. Rev. Gen. Bot. 7: 16-26, 17-84, 123-137, 1895.

This has been proved before,[1] and I have been able to substantiate it with Lake Michigan sand in pots. Rapid changes of temperature act deleteriously on plant growth. This is another reason for a dry soil supporting only the more hardy forms of plants.

The chief points of difference between a moist and a wet soil may be tabulated as follows:—

TABLE V.—DIFFERENCES BETWEEN DRY, WET AND MOIST SOILS.

Condition of soil.	Dry.	Moist.	Wet.
Water for roots.	Too little.	nough for most plants.	More than needed for most plants.
Soluble salts, origina y near surface.	Sometimes leached downward.	Still near surface.	Still near surface.
Soluble salts originally in low layers.	Questionable.[2]	Partly in upper layers.	Partly in upper layers
Humus contents.	None.	Some.	Plentiful.
Oxygen content.	Plentiful.	Some.	Little.
Micro-organisms.	None.	Optimum.	Few.
Nitrates.	Little.	Much.	Some.
Temperature changes.	Rapid and great.	Intermediate.	Slow and small.

Whether it is determined by nearness of the underground water level of by the capillary power of the soil, there appears to be no doubt that the amount of water in the layers near the surface of a soil practically determines the nature of the vegetation in this region. Besides the general discussion of this matter to be found in Warming and Schimper (loc. cit.), the reader may refer to Gain[3] and Hedgcock.[4]

The other hypothesis for explaining these differences in vegetation rests on the chemical differences in the soils shown in the tables of analyses by Kedzie. From these tables it will be seen that the worst sands are not utterly lacking in any salt needed by plants. But it will be observed that there is a difference in the amounts of these salts found in the different soils, and it may be assumed that these differences are great enough to explain the variation in forest type. But the fact that exceedingly small amounts of mineral matter are needed by plants, together with the fact that all the necessary salts are present in considerable amount, makes this hypothesis exceedingly improbable.[5] From cul-

[1]Gain, E., Rev. Gen. Bot.. loc. cit., p. 18.
[2]See footnote, p. 6.
[3]Gain, E., Recherchesur le le physiologique de l'eau dans la végétation. Ann. Sci. Nat. Bot. VII, 20: 63-215. 1894.
[4]Hedgcock, C. G., Botanical Survey of Nebraska: Studies in the vegetation of the state II. Lincoln. 1902.
[5]Since the preparation of this paper a similar conclusion has been reached in regard to sterility in agricultural soils by Whitnet & Cameron in Bulletin 22, Bureau of Soils. U. S. Dep't of Agric., 1903. Also, it has been shown by actual field test that coarseness of soil particles alone can produce a sterile soil, in spite of a plentiful supply of salts. See Livingston, B. E., and Jensen, G. H., an experiment on the relation of soil physics to plant growth. Bot. Gaz. 38: 67-71, 1904.

ture experiments with plants the author is convinced that the vegetation of the worst soils here discussed does not suffer from want of salts.

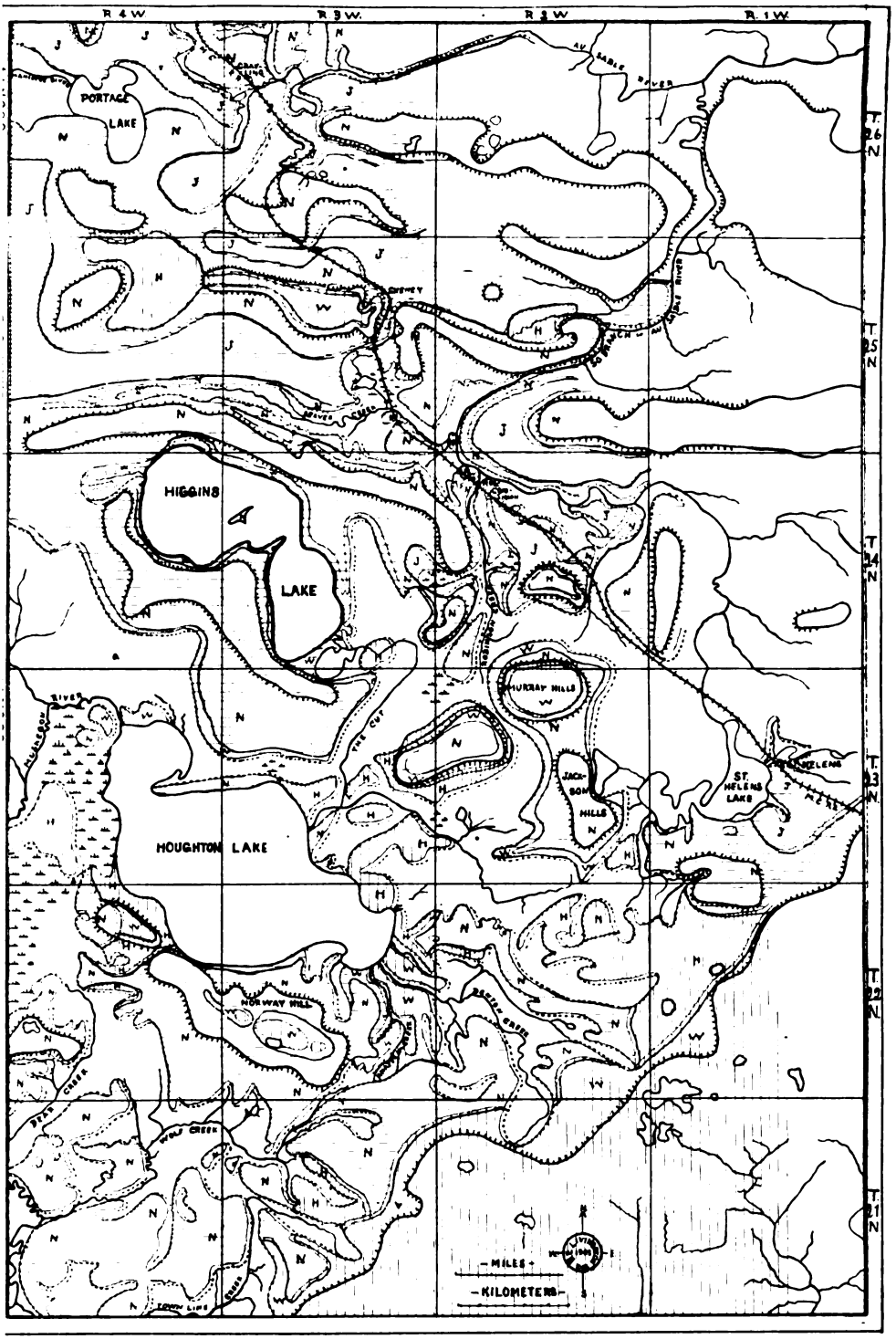
It appears here, as in Kent county, that the hypothesis of Cowles[1] that the nature of the vegetation depends upon the physiographic stage, will hold in a general way. The physiography of the Southern Peninsula of Michigan depends very largely upon glacial topography, however, so that if we wish to trace backward beyond the soils the chain of cause and effect which determine plant distribution here, we come at length upon the purely geological agencies which, at the end of the last glacial epoch, caused one locality to be left a till moraine, another a sandy or loamy one, and still another a sand plain or clay plain, or a pond.

Of the upland series, the hardwood type of vegetation seems to need the most water, the most soluble soil content, and the most humus. Probably this is the reason why this type occupies the moister soils of the uplands, no matter whether these are moist through nearness to the underground water table or through greater lifting power of the soil itself. The types of white, Norway, and jack pine seem to require less water in the order of their arrangement. Probably the Norway and jack require more air in the soil than either the hardwood or the white pine. The typical tree forms of both the last named types occur in the mixed swamp quite commonly, but I have yet to see either Norway or jack pine in soil which is wet the greater part of the year. Throughout the region it seems that each type occupies soils which correspond in water content to its needs. It must be remembered here that a sand or loam soil near the water level may contain much more water than one of loam or clay where the water is farther from the surface. This idea offers, perhaps, an explanation for the occurrence of hardwood on low loam in T. 25 N., R. 4 W. Addition of surface humus has also perhaps, raised the water-holding power of the soil to the neighborhood of that manifested by clay itself. The subsoil is such here that the white or Norway type might be expected.

(b) The present distribution: The statement so frequently met with that the white pine will not come up after it has once been cut off and the ground burned over, seems to strike wide of the truth in this region. The writer visited almost every square mile of the uplands, and he is thoroughly convinced that scattering seedlings of white pine are now evident on practically all areas originally covered by that species, which have not been recently subjected to the action of fires. Seedlings of the Norway are now, however, more numerous on these areas than are those of the white itself. They are plentiful throughout the region on light soils excepting the very lightest. Fires destroy the young growth of the white pine and also prevent humus formation. Thus, as long as the fires are allowed to occur so frequently, the water capacity is not apt to rise and the growth of nitrifying bacteria is not apt to increase. But the presence of the few white seedlings is evidence that the species can grow if protected. Indeed, the best young stands of any kind that I have seen are of this tree, and they promise exceedingly well for reforestation.

As has been said, the Norway is coming in quite freely in the areas originally covered by this species and by the white. The degeneration goes no further, however; I have almost never seen even individual jack pines appearing in any of these areas. Indeed, there is evidence in some

[1] Cowles, H. C., The physiographic ecology of Chicago and vicinity; a study of the origin, development, and classification of plant societies. Bot. Gaz. 31: 73-182. 1901. Idem, the plant societies of Chicago and vicinity. Bull. Geog. Soc. Chicago, 2: 1-76. 1901.



SOILS AND FOREST TYPES OF THE MICHIGAN FORESTRY RESERVE

ROSCOMMON AND CRAWFORD COUNTIES MICHIGAN

LEGEND:

- MORAINE MARGIN
- SWAMP AND CHANNEL MARGIN
- SOIL MARGIN
- VEGETATION MARGIN
- HARDWOOD ---- H
- WHITE PINE ---- W
- CLAY
- CLAY LOAM
- LOAMY SAND
- SAND
- NORWAY PINE --- N
- JACK PINE ---- J

places that the Norway is rapidly advancing its seedlings into the areas held by the jack.

The hardwood forest reappears quite rapidly when cut. This is doubtless in part due to the fact that this material does not burn so readily nor so violently as do the pines. The scattered white pines which formerly characterized these forests in the eyes of the lumbermen, are not returning. They were perhaps only a relic of a past generation of forest.[1] Hemlock is reproducing well and will return with the beech and maple if, through lack of humus, the soil does not become too dry for the seedlings. The sugar maple is best for reclaiming cut over lands. Its saplings stand close together and do not seem to suffer from one another's shade, while they prevent the dying out and oxidation of the surface soil.

The work of Sherrard[2] in this region resulted in a map and statistical study of the tree growth of township 25 N., R. 4 W., as well as a general discussion of the forestry conditions of the reserve. The township thoroughly studied originally contained practically no white pine, but the other types are well represented here. Sherrard's oak flat and oak ridge are all originally Norway land. For statistics of growth, etc., the reader is referred to his paper.

2. *The Lowlands.*

The three types of lowland vegetation seem to follow in some degree the conditions of soil moisture. In this case it seems better, however, to arrange the types in the reverse order, and to present them as following conditions of drainage. As has been stated, all three types are composed of forms which can withstand a great deal of moisture. No positive evidence can be given as to whether or not there is any difference in water content between the soils of the open meadow and those of the tamarack and arbor-vitæ forest. Nothing has been made out regarding the conditions which decide in favor of one or the other of these. But the mixed type is always found on the better drained portions, where there are hummocks raised out of the saturated soil, and where the general level is a few inches higher. Often this better drainage seems to come about merely by accumulation of vegetable debris, a fact which suggests that perhaps in time the conifer swamp might give way to the mixed, and this at last possibly to the hardwood.

Attention has already been called to the fact that this series of types has not been seriously altered by the hand of man. The large white pines have been taken from the mixed swamp, as have also many of the most valuable tamaracks and arbor-vitæs, but the forest conditions have not generally been destroyed.

[1] See the author's Kent county paper, loc. cit., also Whitford, H. N., The genetic developement of the forests of northern Michigan. Bot Gaz. 31: 289-325. 1901.

[2] Sherrard, T. H., The Michigan Forestry Reserve. Rept. Mich. Forestry Commission. 1902. pp. 26-54. 1903.

RELATION OF THIS REGION TO KENT COUNTY.

The predominance of the pines in the region under discussion is an expression of the fact that the flora here is a typically northern one. Only one pine is found in Kent county, and there it grows in poorer soil than it holds here. The presence there of hickory, and the better growth of the black, red, and white oaks, is an indication of a more southern flora. The factor which keeps the jack pine out of the more southern county can hardly be one of latitude merely, for this species occurs along with the white pine on the dunes at the extreme southern end of Lake Michigan.

The hardwood forests of the two regions are very nearly the same in character. In the northern part of Kent county the hemlock begins to play the important part with the hardwood which we find it playing farther north.

A study of the transition zone between these two areas will be necessary before the working out of the exact relation of the various societies can be attempted.

RELATION OF THIS REGION TO THAT FARTHER NORTH.

The student of plant distribution who has formed any definite theories as to the relation of plant societies to topography and soils from working in the southern part of the State and in Indiana and Illinois, will be much surprised, if not actually shocked, by a visit to the region of the Straits of Mackinaw. On the island of Mackinac, for example, occur most of the tree forms found in Kent county, but growing, apparently, without relation to the soil condition. Norway and white pine, beech, sugar maple, red maple, tamarack, arbor-vitae, balsam fir, spruce, basswood, hop hornbeam, etc., will be found growing side by side on well drained uplands, in clay or sand or loam, or even upon partially bare rock. As to why this is, nothing can be said before more of the State has been studied in detail. It is useless to conjecture at the present time, although the problem appears to be a fairly easy one to answer.

THE FUTURE OF THE REGION.[1]

Since there has been considerable discussion in the state concerning the utility of these lands for various purposes, it may be well to consider this subject briefly here. On the uplands most of the different kinds of soil have been tested for agriculture, the clay hills and the clay plains, both of comparatively small extent, make excellent farming land. The gravelly and loamy sand of most of the ridges is easily tilled, and, with enough

[1]This has, in part, already appeared in the report of the State Forestry Commission, loc. cit.

care, yields good crops, but the soil is too light, and the amount of energy necessarily expended in cultivation is much greater than in heavier soils.

On the worst sand plains, originally covered with very open stands of jack pine and scarlet oak, tillage is almost out of the question. With constant manuring and cultivation, this sand can be held in place and made to produce fair crops, but the expense, in time and energy, if not actually in money, make such crops cost much more than they will actually bring on the market. Some of this land is so situated that irrigation would be possible, and this may some time become a practical line of investment. The grazing of cattle on the Norway and jack pine plains is practicable, and is being carried out successfully by several holders in Roscommon county. Several forms of bunch grass and the shade of the scrubby oaks and pines, are the valuable features. But it requires many acres for a few cattle, and it is doubtful whether the small landholder can ever accomplish much in this direction. Practically all the small holders who are succeeding at grazing, are pasturing their cattle, in good part, on the lands of the State and of other individuals.

The swamps which are abundant in the region, would all make excellent garden land if properly cleared and drained. It appears that the most promising use to which to put the swamps is that suggested by A. C. Lane, of the Michigan Geological Survey, namely, to derive fuel peat from them. Samples assayed from 52% to 75% combustible material.

A number of tests have been made of the ability of the ridges and more loamy plains to support apple trees, with considerable promise of success.

The feasibility of reforestation seems practically proved. Every student of plant growth who has worked in the region[1] has become convinced that the main reason for the failure of natural reforestation here lies in the repeated and destructive fires.

With the fire nuisance removed, it is quite certain that nearly all of the upland area would spring up to seedlings of white and Norway pines. Further than this, it seems very probable to the present writer that, if the land which will now support nothing better were kept covered with Norway forest, it would eventually become (through the accumulation of humus) capable of supporting a good growth of white pine, which might be planted among the Norways when the time was ripe for it. How long this process of amelioration might take, it is useless at present to conjecture; there is no locality in the region which is free from fires, and thus no possibility of collecting data for this purpose.

During the past season much advance has been made by the State Forestry Commission on the Reserve. A thorough mapping is in progress, and the fire nuisance has been largely under control.

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[1] A number of such writers are the following:—
Roth, F., On the forestry conditions of northern Wisconsin. Wis. Geol. and Nat. Hist. Survey. Bull. 1. 1898.
Spalding, V. M., The White Pine. U. S. Dept. of Agric., Div. of Forestry. Bull. 22. 1899.
Whitford, H. N., Bot. Gaz. 31: 289-325. 1901.
Sherrard, T. H., loc. cit.
Davis, C. A. Rept. Mich. Forestry Comm. 1902. P. 24-28. 1903.
Roth, F., ibid. P. 34-37.
Skeels, F. E., ibid., P. 40-47.
Beal, W. J., ibid., P. 52-56.
McLouth, C. D., ibid. p. 48-51.

CONCLUSION.

It appears from these investigations that the main factor in determining the distribution of the forest on the uplands of this region, is that of the size of soil particles, the sorting of which dates back, almost entirely, to the glacial epoch. The size of particles determines the amount of air and moisture in the soil, and these in turn determine the amount of humus formation and the growth of nitrifying organisms, and, to some extent at least, the amount of soluble salts.

A factor of less relative importance, because applicable only over small areas, is that of the nearness of the underground water level to the surface. This affects the uplands only along swamp borders.

In a broad way, physiography may be said to determine the vegetational distribution here. The physiographic features depend largely upon glacial topography. Thus geological factors have, in one way or another, determined the nature and distribution of surface soils and the distance below the surface of the underground water level, and so these factors have determined vegetational distribution.

It is probable that many dry soils may at length become moist enough to support one of the more moisture loving types of vegetation, simply by increase in humus content, which must go on slowly at first but more rapidly as the amount of this substance increases. This is merely an application of one of the general principles of forest succession pointed out by Whitford (loc. cit.).

The lowlands are covered with a vegetation which seems to be able to bear excess of water and paucity of oxygen in the soil. From the open meadow and coniferous swamp, we pass, with better and better drainage, through the mixed swamp to the hardwood or the white pine of the uplands.

It appears that the natural reforestation of the pine areas with the Norway, and, to some extent, at least, with white pine, is practicable if the fires can be suppressed. Orcharding gives some promise of success on the ridges and loamy plains, and, together with Forestry, offers probably the best use to which to put this region which contains so little good land for general agriculture.

The New York Botanical Garden,
December 7, 1903.

Dr. L. L. Hubbard's work on the felsitic areas on the end of Keweenaw point gave us such a new idea of their field relations and shows that the earlier geological mapping was so inaccurate that it has been deemed worth while to study a similar area in the Porcupine Mountains in some detail. This was begun some time ago under his direct supervision but has been continued by Mr. F. E. Wright, Assistant State Geologist, last summer. Part of his report of progress is given herewith.

REPORT OF PROGRESS IN THE PORCUPINES.

BY FRED EUGENE WRIGHT.

REPORT ON THE PROGRESS MADE BY THE PORCUPINE MOUNTAIN PARTY DURING THE SUMMER OF 1903.

BY FRED EUGENE WRIGHT.

The Porcupine Mountain region lies in the northwest part of Michigan not far from the Wisconsin boundary line and is located in the townships and ranges:

T. 51 N., R. 42, 43, 44 W.
T. 50 N., R. 42, 43, 44, 45 W.
T. 49 N., R. 43, 44, 45 W.

In all an area of about 230 square miles.

Observed from a distance the Porcupine hills appear as high, steep ridges and knobs rising from 600 to 1,200 feet above the level of Lake Superior. A bird's eye view of the same exhibits a definite arrangement of these elevations and cliffs, so sharply carved on the land surface as to attract the attention of the most casual observer. If examined closely the influence of the geologic structure of the region, the relation of the rock masses one to another is found to have been the chief factor in moulding the topography to its present form.

The rock formations underlying this area consist largely of eruptive rocks of various types and interbedded sandstones and conglomerates belonging to the Keweenaw series. They have been studied by a number of geologists in the past, chief among whom was Irving and his assistants, who in his classical report on the copper bearing rocks of the Lake Superior region,[1] devotes an entire section to the Porcupine district. He describes in detail several of the typical rocks of the region and their relation one to another, correlates strata found here with those of other districts of the Keweenaw series, and gives an excellent geologic map of the area.

Since Irving's report was published work done by later observers, especially by this survey, has brought to light facts which tend to alter to a certain extent the conceptions held by Irving. The present writer, however, desires to reserve the discussion of the conclusions reached by Irving and later geologists until after he himself has covered the entire region. In the following paragraphs the methods employed on the survey in making the topographic and geologic map will be considered briefly and also several of the salient geologic facts which were noted in the course of the summer's field work.

In order to obtain at once a powerful aid in deciphering the geologic structure of the district the survey decided to make a topographic map of the region in conjunction with the geologic map. The geologic structure has had such a pronounced effect on the land structure of the Porcupine

[1] U. S. G. S., Vol. V. Monograph. Pages 206-225.

hills that many important points which are valuable in the structural investigation, can be deduced from a good topographic map alone.

Accordingly the month of May (May 6—June 6) was spent in establishing bench marks along the range and township lines and roads through the townships. During this time the writer had the efficient aid of Mr. G. W. Corey as Wye level man, Mr. W. R. St. Clair as water level man, and Messrs. C. W. Dodge and H. Dodge as rodmen.

A system of closed levels was run with the Wye level from Union bay along the Nonesuch road to the Nonesuch mine and back to the correction line; then W. to S. W. Cor. Sec. 36, T. 51 N., R. 42 W., then E. to the S. E. Cor. Sec. 36, T. 51 N., R. 44 W., and from there N. along the range line between T. 51 N., R. 43 W. and 44 W. to the lake shore. Wye levels also ran from the crossing of the Nonesuch road and correction line E. to the S. W. Cor. Sec. 36, T. 51 N., R. 42 W., closing on the same B. M. that the water level line along the White Pine road closed on. Bench marks were established at convenient points along the road and on every corner along the correction line and range lines. The bench marks were inscribed on trees as follows:

B. M.
M. G. S.
248.21

the number 248.21 giving the measured elevation above the shore of Lake Superior of a notch cut at the base of the tree bearing the inscription. Care was taken to select good hardy trees which will stand for many years to come. The elevation above sea level can be found by adding 601.19 feet to the given altitude. In all 20 miles of line were run with the Wye level. The usual methods of checking to insure accuracy and to prevent mistakes were used. The error found by checking back to the lake was 0.89 feet for 16 miles of rough forest leveling. The level of the lake on the date of departure and arrival of the party was ascertained at the Government Lake Survey office in Houghton. It is probable, however, that the level was not exactly the same for the coast off the Porcupine hills as at Houghton owing to the seiches and tidal influences. The change in actual lake level may have had some influence upon this result. At the very utmost the error of any bench mark is less than one foot and sufficiently accurate for the aneroid work where 50-foot contour lines are drawn.

Besides the exact Wye level work along the correction line, which is to be used instead of lake level in the future work of the survey in the inland townships, a series of closed water level lines were run from Union bay along the Carp Lake road to the Carp Lake mine and Carp Lake with checks N. along range line between T. 51 N., R 42 W. and 43 W. to Lake Superior, and S. along the range line to Wye level bench mark at the correction line. The Carp Lake bench mark was checked by running up from the lake along a logging road in Secs. 9, 16 and 15 and over ridge into 22 of T. 51 N., R. 43 W. The White Pine road along the E. range line of T. 51 N., R. 42 W. was leveled as far as the correction line where a check on the Wye level bench mark on S. W. Cor. Sec. 36, T. 51 N., R. 42 W. was possible. The average error of the water level work was 0.45 feet per mile. The Wye level party were able to cover on an average 0.8 of a

mile daily. The country on the whole was fairly rough and the foliage so dense that long sights could not be taken. An average of 60 turning points were required for each mile. With the water level about twice the distance could be covered in a day or 1.6 miles on an average. In running the level lines through the dense forest it was found necessary to reblaze the section lines and thus clearly mark the path for the leveling parties so that they should not waste time in hunting for old blazes, lines and corners. At the same time future work could be planned most advantageously.

The bench marks thus established served as a basis for the general contouring of the area which was effected by the use of aneroid and barograph. This topographic mapping was carried on in connection with the geologic mapping until the end of the field season (Oct. 1). While accomplishing this latter work the writer had the able assistance of Mr. A. F. Benson as geologist and Mr. W. C. Gordon, Mr. C. W. Dodge, Mr. G. W. Garrey and Mr. C. A. Wright as compassmen, during various periods of the summer.

The lake shore is evidently sinking in the Porcupine Mountain district. The greater part of the coast line is rocky and bounded frequently by reefs of sandstone and conglomerate dipping toward the lake. Along the shore of Secs. 16 and 17 of T. 51 N., R. 43 W. old cedar trees 12—14 inches in diameter are so near the water's edge that their bark for the first two feet has been worn off by the beating waves. They have not reached their present position by individual slipping from the higher protected plane, for the ground immediately behind them is covered by a dense, low marshy cedar thicket. If there had been any slipping the entire outlying belts must be in a similar state of movement as evidences of the sinking of the shore are noticeable along the whole coast line of the map.[1] On the shore S. W. of Lone Rock in Sec. 24, T. 51 N., R. 44 W., dead trees, still upright and firmly rooted in the coarse shingle which lines the coast at this point, stand 6 to 8 feet from the shore and under 6 to 8 inches of water. On the shore of Sec. 17, T. 51 N., R. 43 W. an old fisherman's cabin extends almost to the water's edge. It is apparently on its original site, which, however, must be lower now than at the time of its erection for no fisherman would build a shack within reach of high waves. The old Carp Lake road along the lake shore in Sec. 15, T. 51 N., R. 42 W. had to be abandoned and another built farther inland because of the encroaching lake. Old corduroy stakes slipping toward the lake still mark the course of the former road. A thin belt of swamp and cedar thicket frequently extends along the lake shore for considerable distances (map). Mr. Redner of Bessemer, who has often camped at the old La Fayette landing in Sec. 24, T. 51 N., R. 44 W., states that 10 or 12 years ago the shore of that point was sandy and like the usual Lake Superior beach. At present, all of the finer sand has been washed away and only the coarse shingle remains. Further evidence of the encroachment of the lake on the land is the discrepancy between the lengths of the section lines and shore sections as determined by the original government surveyors and the present survey. The difference is considerable in certain sections. In Sec. 24, T. 51 N., R. 44 W., the shore opposite Lone Rock is low and swampy. The ground 100 paces in-

[1] Dr. L. L. Hubbard in Vol. VI, p. 47 of this survey describes the local slipping of large blocks of sandstone at Bare Hill, Sec. T. 58 N., R. 28 W. due to the undermining action of the waves which destroyed the underlying support. See also Rominger in Geol. Survey, Mich. V, Pt. I, p. 136.

land is not over 10 feet above lake level. At a point 110 paces inland loose shingle was observed covered with a slight coating of vegetable matter and soil. Evidently this shingle was deposited in place by wave action at the times when the lake level was higher than at present. Whether this took place during the period of existence of Lake Superior and is then due to a fluctuating shore line or during the period of the former lakes Great Nipissing, Algonquin or Warren, is a matter of conjecture. The frequent lake terraces at the 100-foot and 500-foot contour level point to old shore lines of the former lakes and render the first idea of fluctation not improbable.

The phenomenon of coastal sinkage in this region was first noted by Mr. Stuntz[1] who cites the sluggish nature of the Ontonagon river near its mouth as evidence. C. K. Gilbert in his "Recent Earth Movements in the Great Lakes Region,"[2] finds that the basin of the lakes has been canted toward the southwest, the exact direction of tilting being S. 27° W. Using the present surface of the lakes as datum plane he bases his conclusions on a thorough discussion of all available data from gage stations, on a series of gage station observations made under his direction on the position of the old shore lines of the vanished Iroquois, Warren, Algonquin, and Great Nipissing, on the observed drowning of streams and formation of wet swampy belts near the shore. In considering the Lake Superior region Gilbert emphasizes the importance of a verification of the observation of Stuntz who found the sinking of the lake shore to be more rapid than that indicated by the gage readings. The establishment of a gage station with a set of precise bench marks near the lake shore would be of great assistance in later years in solving this problem.

In the short time allotted to its work it was impossible for the survey to take up this question and examine it thoroughly and determine, if possible, the approximate yearly sinkage.

Old lake terraces constitute a characteristic feature in certain sections of the Porcupine area. The lake terraces about the 500-foot level are particularly noticeable. On the map of Plate I, the 500-foot contour line follows a sinuous course, completely encircling the range cliffs through T. 51 N., R. 43 W., and also wrapping around the slopes south of this ridge. The appearance of numerous swamps at the 500-foot level in the three townships of the map and the shallow level divide between the N. W. branch of the Union river and Carp river also indicate the presence of a former lake in which the cliffs of T. 51 N., R. 43 W. stood out as bold rock masses. On their N. side the beds of tough conglomerate appear to have imposed a limit on the encroaching waves. At the foot of these north slopes immense blocks and outcrops of this conglomerate are abundant.

Underlying the 500-foot contour belt are sandstones, which succumb easily to erosive agencies. The valley of Carp lake is probably due largely to erosion not of a former river but of the vanished lake which originally covered this area. The sandstones were broken down by the pounding action of the waves, while the more resistent melaphyre belts withstood the process more forcibly and hence stand out at present as imposing cliffs with Carp lake and river valley intervening. The flow of

[1] On some recent geologic changes in northeastern Wisconsin: Proc. Am. Ass. Adv. Sci. Vol. XVIII, 1870. pp. 206-207.
[2] Annual Report U. S. G. S., XVIII, Pt. 2: 601-647.

Carp river from Sec. 19, T. 51 N., R. 42 W. to Sec. 36, T. 51 N., R. 44 W. is slow and sluggish. Carp lake can only be counted as a widened part of the river. It is shallow in all its parts and full of weeds. Why the Carp river coming as it does from the southwest does not continue in its easterly direction and enter the Union river instead of bending sharply to the west is one of the problems still unsolved in this connection. The drainage problem and its dependence on the structure is certain to be productive of bountiful results in the future work of the survey in this district. Faulting, especially dip and slide faulting, may have had more or less influence in causing this valley to assume its present shape. Glacial erosion is another factor to be considered. Glacial boulders of variable size occur in many parts of the area, even along the steep north slope of the range of cliffs in T. 51 N., R. 43 W. No distinct glacial striae were observed, however, during the summer's work.

Evidence of faulting were noticed in Secs. 19 and 27 of T. 51 N., R. 42 W., Secs. 21, 22, 29, 30, of T. 51 N., R. 43 W., and Sec. 36, T. 51 N., R. 44 W. At the foot of the steep north and northeast slopes in Sec. 24, T. 51 N., R. 43 W., and Sec. 19, 20, 29, of T. 51 N., R. 42 W., numerous springs approximately along the 550 contour line indicate strongly a probable fault plane. Union spring, in Sec. 20, T. 51 N., R. 42 W., evidently bears an intimate relation to this probable fault plane. Irving[1] describes and pictures a fault of considerable proportions in Sec. 19, T. 51 N., R. 42 W., along the Carp river—his first mention of a fault in this region. The details of this area, however, have not been worked up sufficiently well as yet to admit of a general discussion at present. Along the cliffs in T. 51 N., R. 43 W., block faulting is apparently common. In tracing a bed of melaphyre along one part of the cliff it is not an unusual occurance to encounter a bed of sandstone in the same horizon. The shattered character of the rock at such points, however, points to a probable block faulting and slipping of one part of the rock mass relative to the other.

At the old Lafayette mine in Sec. 36, T. 51 N., R. 44 W., slide faulting[2] seems to have been the indirect agent which guided the copper to its present resting place. The mine is situated at the base of a steep cliff, the continuation of the series of melaphyre ridges across T. 51 N., R. 43 W. The shafts are sunk along the contact of the melaphyre and the underlying sandstone. The melaphyre from the contact to the top of the cliff is more or less shattered and is full of secondary epidote, calcite, and copper. The slide faulting was used to advantage in sinking one of the three test pits, all of which are less than 75 feet deep. The west wall of the westerly shaft is a slickensided fault plane, vertical and with margins nearly parallel to the dip of the formation (dip about 30° to N. strike N. 50° E.). Neither dip of melaphyre beds nor of strike on slickensides could be determined within several degrees. The copper which has suffered hydration and carbonization colors the wall light green on a variegated background of chlorite. The fact that the copper has likewise been acted upon by the sliding movement indicated that it must have been precipitated either before or during the period of faulting. Epidote veins traverse the face of the escarpment in a plane almost

[1] Loc. cit., p. 215.
[2] Compare Mich. Geol. Survey, Vol. VI, pt. 2, p. 94-96, where Dr. L. L. Hubbard discusses "Topography as affected by slide faulting" in certain parts of the Keweenaw range. Also Dr. A. C. Lane in Mich. Geol. Survey, Vol. VI, pt. 1, p. 33-43, for faults in the Keweenaw rocks on Isle Royale.

parallel to the dip and strike of the rock. The copper appears to be confined to them. The epidote veins show evidences of slight faulting probably due to minor dislocations of the block resulting from inner differential strains in the rock mass in its new position. A second set of minor, nearly vertical epidote veins can also be observed here and there. They are barren of copper and do not cling to the adjoining rock as the larger copper bearing veins. The sandstone below the melaphyre is usually buried beneath the talus debris. It is a fine-grained, dark red, almost quartzitic sandstone, jointed and full of calcite veins. Occasionally threads of malachite may be seen penetrating from the contact into the underlying sandstone. They extend downward a few feet at the most and are evidently a result of deposition from above.[1] In the melaphyre at this location the copper is confined to an epidote zone of fracturing and slipping—as though the conditions which deposited the copper and formed the epidote had found easy access to the clefts of the broken rock. The epidote was formed first, then the calcite and lastly the copper. The periods of crystallization of the three, however, overlapped, some of the copper having been precipitated before all of the calcite had formed. The solutions must have entered at the very outset before much faulting had taken place as the epidote and copper veins show slickensides—are frequently noticeably displaced. Unfortunately large veins were not exposed, on which the amount of slide could be determined, as has been done at several points on the Keweenaw range.[2]

Copper in similar veins was also noticed on the face of the cliff in Sec. 21, T. 51 N., R. 43 W. It is an interesting fact that all the mines in this area have been located at the junction of the melaphyre belt and sandstone, the horizon of the Lafayette mine. The Carp lake mine, the Cuyahoga, the Union, and the Halliwell all owed their existence to the indications of copper observed at this contact, which is readily recognized by the peculiar appearance of the underlying sandstone noted above. The sandstone is frequently interlaced with a network of secondary veins of calcite. Fracture and jointing planes are common and seem to have been produced by the action of the overlying melaphyre.

The Union spring mentioned in connection with the faulting of the region is one of the largest in Michigan. Almost circular in outline, it has a diameter of about 40 paces and is nearly 8 feet deep. The water is cold and unusually clear; it issues from several points on the bottom of the pool near the west end, and keeps the sand in the near vicinity in a state of constant agitation and as if a strong stream of water were ever flowing from underground pipes placed several feet below the surface. The number and position of these points of emergence varies from day to day. On August 31st water was observed coming up from three points while on September 6th, only two points were visible and then in different positions. A full grown stream flows from the northeast end of this spring. It is a remarkable fact that notwithstanding the immense amount of water which passes up through these openings not a single gas bubble is seen to rise to the surface. The surface is still and quiet and does not belie the strong current underneath. At a point about 80 paces below the outlet of the spring a cross section of the stream was taken

[1] Especially noticeable on the escarpment S. W. of the Carp lake mine.
[2] Michigan Geological Survey, Volume VI, part 2, pp. 86-96.

and the average rate of flow measured. From the data obtained a conservative estimate placed the capacity of the spring at over 750,000 gallons of water per 24 hours, enough to supply a village with the purest water obtainable. A well-blazed trail leads from the Carp lake road to the spring (map).

One fact of general interest was observed in the outer conglomerate belt which is well exposed at the mouth of Carp river in Sec. 33, T. 51 N., R. 44 W., where it forms the protecting arm of the small bay used by the fishermen in their summer work. The conglomerate consists of rounded pebbles of various rocks, felsite, melaphyre, sandstone, and occasionally jaspilite. The size of the jaspilite pebbles varies from 1 to 15 cm. in diameter. The nearest known outcrop of jaspilite is on the Gogebic range, and these pebbles were probably transported from there from a distance of nearly thirty miles. It remains to be seen whether the jaspilite in this conglomerate is distributed uniformly or only locally. The pebbles may have been transported by wave action or by a river. At any rate the occurrence of these jaspilite pebbles add an additional proof to the fact that the Huronian rocks were highly metamorphosed and altered, and the iron ore beds largely formed in pre-Keweenawan times; that the time interval between the formation of the Huronian rocks and those of the Upper Keweenaw series was an extremely long one.

The melaphyre belts have a pronounced effect on the compass needle and occasionally change the magnetic variation as much as 10°. It was originally the intention of the survey to use the dip needle as a possible aid in tracing fault planes in the melaphyre. Owing to other work and unfavorable weather this was neglected. The method will be used in the future, however, and its applicability to this region thoroughly tested.

The felsite area was left practically untouched the past summer. In Sec. 19, T. 51 N., R. 42 W., the felsite is rather basic and exhibits long drawn out vesicles and amygdules, the direction of elongation of which is northeast and southwest, the probable direction of the flow of the felsite. The felsite in this case was probably a superficial flow.

The observed fact that all the streams that flow into Lake Superior in T. 51 N., R. 42 and 43 W., are compelled by a sand bar at their outlet to bend abruptly to the west is an interesting phenomenon in connection with the study of shore currents and shore sinkage. On the lake shore of Sec. 8, T. 51 N., R. 42 W., the occurrence of enormous blocks of conglomerate, 20 tons or more in weight (2 meters high), resting on logs, give a good idea of the tremendous lifting power of the lake waves in time of storm. Ice blocks may have assisted in this work. The original point on the conglomerate ledge from which these blocks were broken off may frequently be seen ten or twenty paces distant. A peculiar feature of the drainage in the Porcupine hills is the frequency with which streams of considerable size disappear underground, deserting their old creek bed for long distances, only to reappear further on. In the Little Carp river in Sec. 19, T. 51 N., R. 42 W., excellent examples of pot holes were noticed. Thick beds of red clay are exposed along the Iron river in Sec. 36, T. 51 N., R. 42 W. The roots of upturned trees form in general a flat disk like aggregate which evidently extended into the ground but a short distance. They are shallow roots and indicate a water level near

surface.[1] Deep roots are rare. Outcrops are not common owing to the heavily wooded condition of the land. With the exception of the small clearings at the Carp lake, Union, and Halliwell mines, the land is covered with virgin forest. The trees are hardy and indicative of good soil underneath. The kinds of trees over the various formations differ. The area near the correction line in T. 51 N., R. 43 W., on the felsite is densely covered with hardwood, while hemlock predominates in other parts. At present the only articles raised are oats and vegetables. (These at the Nonesuch mine in Sec. 1, T. 50 N., R. 43 W.)

The distribution of the tree belts is especially noticeable in this district. In certain parts the boundary lines of the various tree belts were so sharply defined that they could be mapped accurately. These belts and the predominating trees in each belt were recorded in the field notes and will probably be made use of in the later report of the region. Several factors enter into consideration in this connection, the habitat of the tree, the discussion of the underlying and resultant soil, the topography as affecting the influence of the sun's rays, the drainage, etc., which tend to make the problem a difficult one. It may be stated that any one interested in the study of fungi (mushrooms), ferns, mosses, and in fact all botanical, zoological, biological problems could find abundant and varied material for investigation among the wooded slopes of the Porcupine hills. During the month of September, Mr. A. G. Ruthven of the Biological department of the University of Michigan, accompanied the survey party and was well satisfied with his results.

The physical condition of the soil and atmosphere vary so rapidly in the various parts of the district that a great variety of forms result.

The quality of the land survey in the Porcupine hills is good. Only one extremely poor survey of a section was found. The line between Secs. 7 and 18 of T. 51 N., R. 42 W., is 500 paces too short while that between Secs. 8 and 17 of the same township is as many paces too long. All section corners in the territory on the map were visited by the survey; those enclosed in a small circle on the map were found in good condition. Two were missing, the southeast and northeast corners of Sec. 30, T. 51 N., R. 43 W. Several later corners have been squared by woodsmen at these two points but the originals have disappeared.

Points of access to the Porcupine Mountains are by way of Ontonagon or Lake Gogebic. The road from the latter place is very poor and serves only as a difficult trail. The road from Ontonagon is good, steel bridges having been erected over the larger rivers by the township board.

Mr. Ruthven remarks:

"The forest about the Porcupine Mountains consists chiefly of hardwoods and hemlocks with an abundance of ferns in the moist places. The loam about the roots of these ferns was found to be the most favorable collecting ground for terrestrial molluscs, although many are found among the moist leaves in wet places. A few were also found in decayed logs.

"The river and creek shells were found, most abundantly, in the pools at the sides of the streams, but *Limnea desidiosa* occurs in the swift water on the very brink of the falls in Union creek. *Valvata tricarinata* was

[1] See Annual report for 1901, Plate V.

found only in Union river, although a careful search was made for it in the other rivers. It occurs here, however, in great abundance, chiefly in the pools and along the sides of the stream where it may be found clinging tightly to the bare sandstone rocks and sometimes in a current so swift as to carry it down stream when its hold is loosened.

"Ontonagon county marks, in this part of Michigan, the northern limit of Cope's Alleghenian district based on the distribution of reptiles and batrachians. The district, according to Cope, is characterized by having no species peculiar to it. This conclusion is borne out by the list above, for all forms collected range both north into the Canadian and south into the Carolinian districts with the exception of *Hyla pickeringii* and *Chrysemys marginata* which do not extend north of Lake Superior.

"In all the rivers of this region, with the exception of the Union, the brook and creek types of molluscs, such as the *Physa's* and *Limnea's*, persist, as the rivers are followed down stream, although in fewer numbers. This, however, is not the case in the Union river. For as this river is followed down, the brook and creek forms give way to *Valvata tricarinata*. The number of individuals of all species of molluscs is also much greater in this river than in the others, both in the headwaters and farther down stream. These differences in the fauna are probably due to the differences in the rocks over which the rivers flow. For the rivers seem to differ in no other way and all open within a few miles of each other. With the exception of the Union, the rivers of this region flow through sandstone and shale, rocks containing practically no lime. They are therefore, unable to support the larger river snails, which require a large amount of lime in the construction of their heavy shells. Union river, on the other hand, drains, on the east, a ridge composed of melaphyre lying between two beds of sandstone. Melaphyre is an eruptive rock which contains a large amount of lime, and, consequently, Union river contains more lime than the other streams explored. A fact which perhaps explains the presence of *Valvata tricarinata* and the larger number of individuals found here."

"Owing to the close proximity of the mountains to the lake, the streams, which have their origin on the north side of the mountains, have cut out each its own channel down to the lake, and only those, which head on the farther slope, unite to form the larger rivers which are compelled to flow around the mountains to find an outlet. As the streams have their origin in mountain springs, the waters are clear and cold, and the currents swift. They have cut deep gorges in the sandstone through which they rush, leaving many little eddy pools among the projecting outcrops on either side. Their bed consists almost entirely of the solid sandstone over which they flow except at their mouths where the currents become sluggish and silt is deposited forming a bottom of mud and debris. The sluggishness of the rivers in the lower portions is due to the formation of the beach across their mouths which, acting as a dam, causes the water of each stream to spread out into a small lake or pond. On the edges of these ponds, the typical pond conditions are reproduced, as is shown by the rushes and sedges, and fauna of the dragon fly larvae and tadpoles. This gives rise to a curious mixture of pond and river conditions, and a consequent intermingling of the faunas characteristic of each habitat."

[1]See Sixth Report Mich. Acad. of Science, p. 190.

Mr. Walker, in a letter, commenting on the molluscs of this region says:—"The fauna of Ontonagon county is very similar to that of Marquette county around Huron mountain, but the list is not so large owing to the fact that Huron mountain has been thoroughly worked. The fauna is essentially a northern one, the country not being far enough west to be affected by the upper curve of the Transition Zone which, according to Merriam, touches the southwestern extremity of Lake Superior. Just where this line is to be drawn, however, is, I imagine, a very dubious question.

SUBJECTS.

We next proceed to take up various subjects of geological interest upon which work has been done throughout the State.

HYDROGRAPHY.

The systematic collection of well records all over the State has been continued with the efficient aid of the Michigan Press Clipping Bureau. From June to October, Mr. W. F. Cooper was detached to work under Mr. M. L. Fuller of the U. S. Geological Survey, the hydrographic division, in a special examination of the lowest and most thickly settled tier of counties. His report is as follows:

WATER SUPPLY OF THE LOWER PENINSULA OF MICHIGAN.

W. F. COOPER.

In Water Supply and Irrigation Papers of the U. S. Geological Survey, numbers 30 and 31, Mr. Alfred C. Lane has published the results of his investigations in the Lower Peninsula of Michigan, the date of publication being the spring of 1899. Since that report was printed a large amount of information has accumulated. In this report of progress it is not intended to cover all the results already enumerated in Mr. Lane's report, although I have used all the well records upon which his report was based. In this report it is also intended to state the results given statistically in the administrative report submitted at the end of the fiscal year 1903, at which date 408 additional schedules had been obtained relating to detailed and general information upon the Water Supply of the Lower Peninsula. The data obtained in the office during that time are relative to springs, flowing wells, wells in which the water does not reach the surface and water supply or supplies for cities and towns. During a portion of June, July and August, 1903, detailed field work was carried on in the southern tier of counties, including Lenawee, Hillsdale, Branch, St. Joseph and Cass. The results of this field work will form a separate part of this report, the first portion relating to flowing wells, springs, and the sections of several wells in which the ground waters do not reach the surface.

CHAPTER I.

ARTESIAN WELL AREAS.

In the artesian districts here described, it should always be held in mind that our information is not always complete. On the other hand, in places where artesian flows are described as occurring, there are generally only certain wells (it may be only one well out of many) where the water reaches the surface, such a well generally being found on low ground. While in several places flowing wells are found scattered continuously over a large extent of territory, being either bunched together, or forming a considerably elongated basin, it will rarely if ever be true that such an area is entirely continuous. In such basins the flows are generally found in the lower ground, while on the higher ground the water may be several feet below the surface. In such cases they may best be described as semi-artesian. Without minute contouring actual artesian areas cannot be satisfactorily located, and scarcely then without a more complete knowledge of the Pleistocene. In the case of flowing wells from the bed-rock it is possible to obtain much more satisfactory data. When the elevation of the surface is contoured, the dip and thickness of the water bearing strata determined, it will be possible to present more satisfactory determina-

tions on account of the greater stability of conditions under which the water bearing formation was deposited. In this connection Mr. Lane is of the opinion that the Marshall sandstone will furnish artesian flows in valleys north of Lansing for a considerable distance. With these limitations in mind the following artesian basins are described, the greater part being from the Pleistocene.

In Monroe county, Prof. W. H. Sherzer has described[1] an area of artesian water which includes the northeastern part of Ida township, T. 7 S., R. 7 E., the northwestern part of LaSalle township, T. 7 S., R. 8 E., and the southern portion of Raisinville T. 6 S., R. 8 E. Another area in the same county extends south of Frenchtown, through Monroe and the northern part of Erie township, T. 8 S., R. 8 E. Forming a trend in the same direction flowing wells are found at Rockwood, Wyandotte and Delray in Wayne county, being approximately along the western shore of the Detroit river and its outlet. West of and parallel with this area, Prof. Sherzer who is engaged in the preparation of a report on Wayne county informs me that the area he has described in Monroe county is continued as follows: "A second belt extends northward, the prolongation of the artesian areas in the northeastern part of Monroe county, into Huron (T. 4 S., R. 9 E.,) and Brownstown (T. 4 S., R. 10 E.) townships, and reaches up into Springwells (T. 2 S., R. 11 E.), just west of Detroit. There are two or three wells on Michigan avenue, but none any distance north. They seem to fail because of the moraine which leads northwest from Detroit and has too high an altitude to permit flow."

Mr. Frank Leverett informs me that:—"F. B. Taylor calls this an interlobate Huron-Erie moraine and his Detroit moraine leads in from Mt. Clemens as shown in Water Supply paper No. 30, plate 2." In Brownstowns and Huron townships the wells will average 25-30 feet. They generally carry Cl, Ca, Fe, and S. In the district described as artesian in Monroe county, water is sometimes found 8 feet below the surface, but this may be due to lowering the water level since the report was printed.

In Macomb county east of the Detroit moraine (See Water Supply paper No. 30, U. S. G. S., plate 2) artesian water is struck at Roseville and Lakeshore in Erin township, T. 1 N., R. 13 E., at Mt. Clemens, New Baltimore, and New Haven and also near Adair in St. Clair county. At New Haven the wells are from 18 to 30 feet deep. How far north this area is continued has not yet been ascertained. In Erin township this strip of county extends 5 miles west of Lake St. Clair. Mr. Wm. G. Kern, a driller living at Roseville writes that rock (Antrim or Ohio Devonian black shale) is generally struck at a depth of 110 to 150 feet. He gives the following section of the drift from that locality:—

Erin township.	Feet.
Yellow clay	10-20
Strong blue clay	40-50
Putty blue clay	20-50
Sand or hardpan extending to rock.	

Under that either sand which is water bearing, or hardpan which usually extends to the rock. Throughout this area gas often accumulates

[1] Michigan Geological Survey, Volume VII, Part I.

from the decomposition of the Antrim shale and may produce artesian flows. The water is also often strongly sulphuretted.

On the east side of the Port Huron-Saginaw moraine there is an area adjacent to Port Huron where flows have been struck between the moraine and the present shore line of Lake Huron. In this territory flowing wells are found very restricted at Port Huron, Wadham, North Street, Atkins, Zion and East Greenwood in St. Clair county, while in Sanilac county artesian reservoirs have been tapped at Lexington and Minden City. This area is from 3 to 4 miles wide and adjacent to Lake Huron. It is probable that flowing wells could be obtained at various other points in that area above the Coldwater shale, which is a poor producer of water.

Another artesian basin extends in a northeasterly direction, and more or less parallel with the eastern flank of the Deflance moraine lying south of Adrian and water rises nearly to the surface over all of the southeastern part of Lenawee county. There are flows as far southeast as Ogden Center, Blissfield and Britton. "In Milan township, Monroe county (T. 5 S., R. 6 E.) Mr. Frank Leverett states that there are 40 wells or more in the narrow strip just below the Arkona beach between the village of Milan and section 30 Milan township, which range in depth from 10 feet to 84 feet, all from sand and gravel beds below till. The level to which water rises is about 690-695 feet A. T. There are about 50 flowing wells in a district along and near the Belmore beach between section 31, T. 4 S., R. 6 E., and section 15, T. 5 S., R. 5 E. that are from 35 to 160 feet deep. The deepest ones are from the rock, but those 130 feet or less are from sand and gravel below till. The head in this second district is 740 feet A. T. more or less. There is another small flowing well district east of Saline river extending from section 28, T. 4 S., R. 6 E. northeast along the Belmore beach to section 23 of the same township with a dozen or more wells 125 feet more or less in depth, with head about 740 feet A. T. Some reach the top of the rock. There are three flowing wells 50-80 feet deep in section 17 T. 4 S., R. 6 E. with head about 750 A. T."

There are artesian flows at Ypsilanti in the low river bottom at about 680-690 feet. Those at the water works are 62 to 63½ feet deep and have a head not more than three feet above the surface. Concerning the extension northeast from here in Wayne county Prof. W. H. Sherzer writes as follows:

"The most westerly basin lies just east of Belmore beach, no wells being found on the beach or to the west in Wayne county except at Northville as indicated below. The wells of this belt are mostly confined to a belt 3 or 4 miles eastward of the beach and the head is between 710 and 735 feet A. T. There are breaks in the belt, wells being most numerous in Canton (T. 2 S., R. 8 E.) and the southern part of Plymouth (T. 1 S., R. 8 E.) townships. As I remember it a good average would be about seventy feet for these wells. Nearly all give more or less salt, some being so strong that the water cannot be used. Lime is unevenly distributed, some having so little that the water is soft, others carry a considerable amount. Almost or quite all have iron, occasionally also sulphur. Sulphates are very generally absent or in traces only. The flows at one time were much heavier, but owing partly to the increasing number of wells and their filling up with sand, the flow is much diminished. Some are reported able to rise 20-25 feet, but others barely reach

the surface. The temperature averages about 51° F., with a range of about 3°, on either side." In this territory the flows are situated between Denton and Plymouth. There is another district at higher altitude near Northville, 775-800 feet. In Oakland county I believe this basin is continued in the southern and southeastern part, where flows are found at Farmington, where the head is 700-730 feet; at Franklin, head about 760 feet; at Birmingham and Rochester where the head is 750 feet. Thence in the same direction in Macomb county at Washington, 710 to 740, Armada is about 760 feet, and Memphis 760 feet more or less. Mr Lane adds the following note: "In general on the lakeward side of the till ridge in the lowlands, or close to a well marked drop in the topography, flowing wells are liable to occur." Prospectively then we would expect to obtain flowing wells in the territory above mentioned, the distance varying in the lowlands between the moraines, but hardly exceeding 6 miles in width.

It will be observed that this belt is approximately parallel to the one previously described, but extends father north, the ice having retreated toward Lake Huron basin in the meantime, thus forming a greater extension of the basin in which flows would be produced. At Plymouth in August, 1892, Dr. M. V. B. Saunders drilled a well with medical properties, the flow being struck at a depth of 97 feet. John E. Clark, professor of chemistry and physics in the Detroit College of Medicine, made the following analysis.

Analysis of Plymouth well water.	Grains to the U. S. gallon.
Chloride of sodium	14.384
Sulphate of sodium	.372
Bi-carbonate of sodium	5.276
Bi-carbonate of potassium	1.730
Bi-carbonate of calcium	5.471
Carbonate of magnesium	2.906
Alumina and ferric carbonate	1.736
Silica	.500
Organic and volatile	1.298
Total solids	33.673

Carbonate of lithium, present, amount not estimated
Carbonic acid gas, not estimated.

The remedy has proven efficacious in stomach, kidney and bladder troubles.

Birmingham which is situated in T. 2 N., R. 11 E. has obtained numerous flows in sand and gravel varying in depth from 60 to 150 feet. The amount of flow varies from 3 to 150 gallons per minute, being somewhat inversely greater according to the depth of the well. The temperature is 50°. Imlay City is situated between morainic ridges, and so are Attica and Lapeer, and flows are obtained at each of these places. From Lapeer a flowing well tract leads southwestward past Farmer's Creek to Ortonville in the northern part of Oakland county. Concerning the flowing wells at Ortonville, Mr. Leverett sends the following note, based on statements made by R. E. Cassedy, well driller: "There are about 100 flowing wells at and near Ortonville 35 to 70 feet deep from sand under a bed of

blue clay. The strongest well flows 40 gallons a minute from 1¼-inch pipe, but these strong flows are found only in the ravines along Kersley creek, and the head there is 18 feet above the surface. On the plain each side of the ravine, the head is only 1 to 4 feet above the surface and flows are weak." "The deepest well in Ortonville is at Mrs. Storms Arnold's, the depth being 149 feet. No rock was struck." "Northwest of Ortonville, in the western part of Atlas township, T. 6 N., R. 8 E., Chas. Cheney has a well 111 feet deep in which some coal was found at about 105-108 feet. First rock at 98 feet. Water flows two feet above surface and is a hard water well, 3.5-inch with casing."

West of Ortonville in section 5 of Groveland township, T. 5 N., R. 8 E., Jas. Algoe has a flowing well 118 feet deep, that did not reach rock. The head is 10 feet above the surface. Altitude of well about 900 feet A. T. It fills 1¼-inch pipe full at a height of 4 feet above the surface." At Thornville southeast of Lapeer flows are also found in a drainage valley off the moraine. At Lapeer the city water works has from 5 to 8 wells, and pump from 300,000 to 500,000 gallons every 24 hours, with a very little lowering. The water was found at a depth of 280 feet in the drift. An analysis of this water has already been given in Water Supply paper No. 31.

In Washtenaw county flows are found at Ann Arbor, Fredonia, Sylvan and Manchester, from gravel beds in the drift. At Brooklyn in the southwestern part of Jackson county there are flows from the rock, and at Trumbulls west of Jackson artesian wells have been drilled. At Marengo and Albion in the eastern part of Calhoun county there are also flows which are used for a city water supply in the latter place. Parma which is situated between Albion and Trumbulls has no flowing wells. The basin is probably quite localized. In the well put down for the Albion water works in 1902, the depth of the well was 175 feet, and the flow, which was obtained from the Marshall sandstone, amounted to 300 gallons per minute. This formation is famous as a good water producer in the greater part of its basin in lower Michigan. In a later part of this report will be found 13 analyses made by Prof. Delos Fall from wells in Albion. They originally appeared in a supplement to the Albion Recorder.

The flowing wells at Brooklyn are also from the eastern side of the Marshall sandstone area and occur at a depth of 40 feet in the rock, which is said to outcrop on the farm of Geo. Knowles.

The Ann Arbor Water Company has kindly furnished me with the log of a well situated in the city limits, being section 29 of T. 2 S., R. 6 E.

Boring for Ann Arbor Water Co.	Feet.
Surface	12
Quicksand	33
Dry gravel	3
Dry gravel and stones	12
Clay, hardpan, and layer of sand and cobble stone	25
Quicksand	5
Blue clay	5
Hardpan	12
Fine water gravel	7
Clay hardpan, gravel and streaks of water sand	9
Total	123

Geographically there is an area which extends in a southeasterly direction through the eastern part of Allegan, and through Barry county as far as the northwestern part of Calhoun county. From the last named place flowing wells are found in a northeasterly direction through Eaton, Ingham, Clinton, Livingston and Genesee counties. This territory does not form, that is it is not one geological basin in either the Pleistocene formation or the underlying sedimentary rocks. Flowing wells may, however, be found in the low ground in the territory above named, (but that is quite prospective). Flows have, however, been found in Allegan county at Burnip's Corners, Moline, Wayland, Hopkins and Otsego; in Barry county at Hastings, Pritchardville, Prairieville, Hickory Corners and Assyria, as well as at Bedford in the northwestern part of Calhoun county. In Eaton county at Bellevue, Olivet, section 8 of T. 2 N., R. 5 W., Petreville, Potterville, Windsor and Millett artesian basin or basins have been tapped. In Ingham county there are flowing wells at Stockbridge, Leslie, Eden, Mason, Leadley's, Dimondale, Lansing, Okemos, Meridian and Webberville; in Clinton county in the basin of the Lookingglass river at Wacousta, DeWitt and Bath; in Shiawassee county at Shaftsburg, Morrice, Byron, Burns, Durand, Vernon and Owosso; in the northern part of Livingston county at Oak Grove and Madison; while in Genesee county, Flushing, Flint, Atlas and Davison are represented. As thus defined we have a broad segment of a circle swinging three-fourths across the lower peninsula, and doubtless including several local basins.

At Burnip's Corners it is 5 miles to the nearest flowing well; one or two deep wells drilled without obtaining water; the usual depth of water being from 15 to 45 feet deep, being in coarse gravel.

At Wayland flowing wells are 30 to 60 or 20 to 200 feet deep, all under strata of clay, except one which is through into the Marshall sandstone.

Hastings with a population of 3,000 has such a supply that the pumps cannot lower it. At or near Petreville there is a flowing well with medicinal qualities, 165 feet deep. The flow rises 19 feet above the surface. Near Potterville there are two wells, 40 and 150 feet deep with an ample flow, the water being hard and alkaline.

The flows at Dimondale and Millett are in a tributary of the Grand river.

At Leslie, Mr. Arthur J. Tuttle has kindly sent me a record of the strata passed through in his two wells, which is as follows:

Tuttle Wells at Leslie.	Feet.
Drift	30-40
Slate	60-70
Sandstone	10

A softer bed of sandstone was penetrated by the drill at this depth which caused the water to flow just to the surface. Below this a flint rock (probably $FeCO_3$) 2-4 inches, and then sandstone to 160 feet underlaid by a honey comb rock filled with water which rose 10 feet above the surface. This well was drilled by Frank Dodge in 1899, while an earlier well which flows was made by Sanford Bros. of Jackson, Mich., about 1868. The wells flow about 3 barrels per minute. The temperature of the water is about 54° and is slightly mineralized with iron and sulphur. An analysis has been given by Mr. Lane in Water Supply paper No. 31. The beds of coal measure sandstone in which these wells

are found are more or less local in deposition and while almost always water-bearing would not furnish flowing wells where the top of the drift accumulation is higher than the head of the water in local synclines. Mr. Lane in his report on coal,[1] has represented a continuous bed of sandstone running from Leslie to Lansing along the Michigan Central R. R., which would probably furnish flowing wells in the lower reaches of the Grand river basin, including here more particularly Sycamore creek and its tributaries.

At Mason a number of wells have been put down for the city water supply, of which the following will serve as an example:

Well at Mason, Mich	Thickness.	Feet.
Surface	3	3
Gravel	2	5
Water gravel	1	6
Gravel and sand	14	20
Hardpan	8	28
Hardpan and shale	4	32
Fire clay	2	34
Black slate or shale	10	44
Lighter shale	10	54
Hard rocks	2	56
Sand and water	31	87
Sand rock	16	108
Slate	12	112
Sand rock	6	118
Light shale	6	124
Light sand rock	5	129
Shale	2	131

This is in the coal formation, underlying the central portion of the lower peninsula of Michigan.

The mineral well at Lansing is from the Marshall formation. Mr. Lane has given an analysis in his Water Supply paper No. 31. At Flint, Mr. C. B. Berry, medical director of the Oak Grove Sanitarium, has given a section of the beds passed through.

	Feet.	Inches.
Clay and gravel	33	
Sand rock	85	
Flint rock		8
Black slate		10
Coal		10
Slate	2	
Hard sand rock	15	
White slate	5	6
Flint rock	0	8
White slate	9	6
Sulphur rock	0	7
Blue slate	16	
White slate	0	6
Blue rock	28	
Sand rock	67	6
Total	265	

[1]Mich. Geol. Surv., Vol. VIII, Pt. 2.

The water is obtained in the basal bed of [Marshal. L.] sand rock passed through. The flow is 9 gallons per minute.

Along the first correction line of the U. S. Government Linear Survey there is a broad belt where flows have been struck at numerous places. In Tuscola county there are flowing wells at Cass City, Novesta, Wilmont, Mayville, Caro, Akron, Wisner, Fairgrove and Gilford. At Caro a well having a capacity of 400,000 gallons per day was struck at a depth of 274 feet. The water at this depth is pronounced excellent for drinking or other purposes, and its temperature 47°. I believe that Mr. Lane recommended that Saginaw obtain its water supply from this vicinity. Such wells as this might prove a solution of the problem if the supply is permanent.

Prof. C. A. Davis, who is engaged in the preparation of a report on the geology of Tuscola, has kindly sent me the following notes:

" (1) Beginning with the Bay shore and working inland is a region from 4-6 miles wide, in which most of the wells which go into the rock are salt or at best strongly brackish. The district is flat and clayey (clay till or lake clays) to the rock surface, with here and there low sandy tracts or ridges scattered over the surface. From some localities boulders and thin layers of gravel are reported on top of the rock and this overlaid by compact clay or hardpan. The hardpan is generally reported, whether the boulders are or not. This belt runs from a point about a mile north of Unionville where there is a brackish well, southwest through Akron township, includes practically all of Wisner, the northwest corner of Fairgrove and about all the northwest half of Gilford, with the deeper wells salty or brackish, less so to the east, however, along the south line of the township, clear across the township to the east. In Denmark township, brackish water is found along the north border from the northeast corner of section 3 westward, and southeast half of 2, thence westward in deeper wells though some of the shallower areas are not brackish. South of this are no brackish wells until the southwest ¼ of section 16 is reached. There are brackish wells also on the west side of 21 and on the south side of 30, but none east that I found, and the brackish water is practically out of the county in the southwest corner of section 31 of Denmark township, although a deep well at Vassar of more than 400 feet depth is decidedly brackish.

"Throughout this belt there are numerous flowing wells, but many others do not flow and never have, while some used to flow and have stopped, as the number of wells put down has increased. It seems possible that these brackish waters came from the coal measures and from the shales and finer sandstones or even from coal strata as is sometimes reported. The flows from these wells where they flow at all are seldom large and often are very small and feeble, and there is frequent testimony that the head has lowered perceptibly, all, of course, showing that the basin from which they come is not of large extent or is poorly supplied with water, the latter being most probable from the character of the rock, which is not porous. Near the edge of this formation where it overlies the sandstones below, it sometimes happens that the sandstone is reached and then large flows result, which although salty or brackish, are sometimes manifestly getting the salt from the overlying strata since the owners report that before they pulled the casing out the water was much fresher, or entirely fresh. In some cases I advised casing down through the rock to near the bottom of the hole to shut off all water except that from the

sandstone, and the quality of the water was improved by this means in two wells under my observation.

"(2) East of this salty belt and sharply distinct from it in the character of the water, is another tract elongated to the south west and extending nearly parallel with the border of the bay, in which the water is very fresh and free from both lime and iron salts, only traces of any mineral water being found in it. The water comes from sandstone in these wells, and because of the abundant supply of good water easily obtained there is a great development of drilled wells in the west side of Columbia township and in the east half of Akron and southward through Fairgrove. Here the rock is from 70 to 100 feet below the surface with local valleys and depressions in the rock surface which makes some greater depths. Most of the well records show some coal or black shale and it is fair to infer that the sandstone is, in part at least, Carboniferous, but to the eastward it seems possible that this runs without any marked division into the sub-carboniferous sandstones which crop out in the Cass river valley. There are some local faultings in these rocks which may complicate matters geologically, but there is no evidence that such faults affect the water supply, that I have been able to discover. The flows in some of the wells from this belt are large and strong but there is no great head and 3-4 or possibly 6 feet would be the average maximum height above the surface to which the water would rise when I visited the wells, though an occasional well, usually in a depressed place would be reported as rising 10 or 15 feet when piped up that far. On the other hand it was a common occurrence to have the report that the well formerly flowed but stopped when another one was put down near by. It seems probable that the sandstone is more or less discontinuous in this area since some holes have been put down which gave no water at all and the beds of sandstones were interbedded with shale in many of the records. It is certain that in some wells greater depth is reached than in others but whether this means that the water always came from the greatest depth reached by the drill, of course we have no means of knowing. This belt extends northeast into Elmwood township and southwest into Fairgrove and Gilford and Denmark, but on account of the occurrence of morainal and beach ridges to the east it is frequently true that the land surface is so far above the rock, and the head, that while the water rises some distance in the well tube it does not flow. A high morainal ridge runs down from Gagetown to Vassar and along the foot of it to the west and strong beach lines which of course act as reservoirs and give abundance of water in the form of springs so that the deeper wells are not needed. On the moraines the wells are mainly shallow since the till is gravelly and water-bearing gravels are common and productive enough for domestic uses. In Cass valley there are great deposits of gravel and sand, in which good water is abundant and here also no deep wells are put down until Vassar is reached. Here there are a group of wells in the river valley 40-60 feet deep all in the sandstone, from which the city supply is taken. There are also some private wells in the lower part of the town. The flows are all on the river terraces, and the water is free from salt and mineral matter. Near the P. M. R. R. station, or rather the junction of the M. C. and P. M. R. R., is a deep well, which flows a large steady stream, but I was unable to get a record of it as the former owner was dead and the record lost. It was said to be 400-600 feet deep, probably

to the Marshall sandstone. This is drinkable but salty and unpleasantly full of other minerals.

"Southwest of Vassar, at and near Tuscola village, is another group of flowing wells in the river valley. These are shallow and from the Carboniferous sandstone. They are from 40 to 70 feet deep. South of Vassar about 7 miles are a few flowing wells along the foot of the water laid moraine, that comes down from Millington and across Arbela township from about the middle of section 13 to 31. These do not reach the rock but the flow is from gravel below the till on the north side of the foot of the moraine. There are only two or three such wells that I could learn of. Most of the rest of the county is either too high to have flowing wells, or too sandy to need them, the water supply coming almost exclusively from dug wells, throughout the township south and east of the Cass valley, and where these are not sufficient as on the moraine in the southeast corner of the county the elevation is too great to secure a flow, and there are very few drilled wells in that entire district."

Since the report on Huron county was printed seven wells have been drilled by the Coryell Drilling Co. at Bad Axe, which are said to be able to produce about 4 million gallons of water every 24 hours, the Marshall sandstone being the source of the supply. These flow at times.

In Saginaw county flowing wells are obtained in almost any locality, except that in the southern part of the county they are rather restricted to the river valleys. At Chesaning an abundant supply is obtained from the Coal Measure sandstone which is utilized for the village water supply. Also at Fergus, St. Charles, Swan Creek, Merrill, Burt, Birch Run, Blackmar, Frankenmuth, Bridgeport, and at numerous other places flows have been obtained either from the drift or the underlying sedimentary strata.

In Bay county artesian water is found in sections 1, 2, 3 and 12, Williams township, T. 14 N., R. 3 E., in sections 7 and 18 of Monitor township, T. 14 N., R. 4 E., while recently Mr. Theodore Archambeau while drilling for coal in the valley of the south fork of the Kawkawlin river tapped a flowing well near the line of sections 3 and 10. Also in Kawkawlin township there are flowing wells at the corner of sections 29, 30, 31 and 32, which is the remnant of a larger basin which opened out to the east, extending as far as the north fork of the Kawkawlin river. In Beaver township, T. 15 N., R. 3. E., this area embraces parts of sections 33, 35, 26, 28, 21, 23, 14, 15, 11, 12, 2 and 3, the greater part of the basin being adjacent to the south fork of the Kawkawlin river. Also in Kawkawlin township there is an area between the State road which follows the Algonquin beach line and Saginaw bay, where flows are obtained as far south as section 23, T. 15 N., R. 4 E. On the west side of the State road this area is extended into sections 3-5 of the same township. Fraser township T. 16 N., R. 4 E. is abundantly supplied with flowing wells in the area adjacent to Saginaw bay and east of the State road, the same area being extended up Michie creek and into sections 4-6, 8-10. This latter area extends northward into Pinconning township, T. 17 N., R. 4 E. the greater part of the basin being in or adjacent to sections 33, 28, 22 and 15, thence swinging southeast through sections 14 and 23, where the Saginaw bay area is met, an angle with the State road and passing into the bay in section 7, T. 17 N., R. 5 E. To the south of the union of these basins the area adjacent to the bay extends down into Frazer township. An isolated area is in the southeastern part of section 10, T. 17 N., R. 3 E. Most of these wells are in the drift, and are found in gravel or a sandy

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gravel overlying the rock. The following section taken from a test hole record for coal will serve to illustrate the stratigraphy of the deposits; the record being in the N. E. ¼ of the S. E. ¼ of section 24, T. 15 N., R. 4 E.

		Total.
Sand	25	25
Clay	35	60
Sand	4	64
Gray shale	15	79

Mr. Floyd D. Owen has given the results of analysis of Bay county waters in the report of the State Board of Geological Survey of Michigan for the year 1902.

In the deep well at the plant of the North American Chemical Co. at South Bay City, a flowing brine was struck in the Berea grit at a depth of 2,170 feet, the flow amounting to 1.25 gallons every 3½ minutes. An analysis has been given in Water Supply paper No. 31.

In Arenac county the Bay county basin is continued with interruptions flows being found at Standish, Omer, Twining, Turner and AuGres. The prospects for obtaining flows adjacent to the bay and east of the place above named is fair. Furthermore in Iosco Co. at Whittemore, Alabaster, East Tawas and AuSable, flows have been obtained both in bed rock and the Pleistocene; while in Alcona county at Killmaster and Alcona, and at Alpena, there are flowing wells, the greater part of the flows being adjacent to the shore of Lake Huron.

At West Branch, Rose City, and thence north to Indian River there are flowing wells with a great abundance of flow. These lie in basins between high moraines, which have been described by Mr. Lane in Water Supply report No. 30.

Returning again to the south we find in the basin of the Maple river artesian wells at Ashley, Hubbardston, Pewamo and Muir, situated at its junction with the Grand river, with Ionia and Lowell farther down stream. At Ashley the flow is found 260-278 feet with 3 feet head, temperature 52° F. Again at Hubbardston a flow was struck in a sand and gravel bed of the Pleistocene at a depth of 210 feet, where the water rose 20 feet above the surface. The flow at Pewamo is ample and occurs at a depth of 35 feet, while at Muir 5 miles west J. Hale and Sons obtained flows at a depth of 240 feet and another at 300 feet, showing the great variability of the Pleistocene from which these waters were obtained. At Ionia, Mr. H. R. Welker writes me that he struck flows at 27 feet, in the drift and at 313 feet in the bed rock, the flow increasing to a depth of 320 feet.

In the basin of the Pine river at Alma, Breckenridge and Pleasant Valley there is a bunch of flowing wells. "At Alma in 1897, the entire number of flowing wells in the town was 76, of which 9 had a depth of less than 50 feet, while 7 were over 100 feet deep, the greatest being at the Sanitarium engine room, which is 144. The depth of 13 is unknown, while 37 range in depth from 55 to 80 feet. The greatest flows occur at a depth of less than 100 feet as the following table will show:"

	Feet deep.	Barrels per day.
Brainard's	49	634
Strubele's	71	532
Fullerton's	62	450
Pringle's	85	450
Hutchinson's	55	270

In this connection I cannot do better than quote an article which appeared in the Alma Record, Friday, Sept. 10, 1897, prepared by a student of Alma College, under the direction of Prof. C. A. Davis, regarding the wastefulness of the drinking water supply. "Allowing each individual in Alma and Ithaca three pints of water per day, the little well near Clubb's shop would be sufficient for both towns. Assuming that the 71 unmeasured flows are as strong as the ones just referred to, the whole amount of water that issues from the earth within our narrow limits is 222 times what we use, and would slake the thirst of Detroit, Grand Rapids and Toledo. What a waste of water! Eventually the underlying fountains will be drained down to the level of their lowest outlet, and we shall have to scrape acquaintance with the pump handle." In such cases nature exacts her own remedy. For when the flow falls below the surface the basin has an opportunity to become refilled. However, as suggested in the article, it is better to introduce the stop-cock or the simple round plug with a small hole.

At Pleasant Valley in the southwestern part of Midland county the flows occur in interstratified beds of gravel and are found at depths varying from 26 to 60 feet. This portion of Michigan is all deeply covered with the drift.

North of Pleasant Valley there is another artesian area around Alamando and Coleman, in the northwestern part of Midland county, and in the basin of Salt river tributary to the Tittabawassee. In Gladwin county north of there, numerous flows are found at Beavertown, Gladwin, Wheatley, McClure, section 6 of T. 19 N., R. 2 W., and at Butman. The probability of finding flows in Range 2 west of Gladwin county is excellent, as well as in R. 1. W, township 19 and 20 north. At Gladwin water was found in sandstone at a depth of 350 feet, the flow amounting to 100 gallons per minute. Mr. Geo. Shaley, engineer of the Gladwin water works, informs me that small flows are also found there in the drift at a depth of 100 feet.

In Isabella county at Loomis and at Clare just across the line in Clare county, flows have been obtained. Also at Mt. Pleasant, Jordan, Leaton, Rosebush, Brinton, and Sherman City in Isabella county the same water supply is obtained, as well as at Barryton, a short distance west of Sherman City, in the northeastern part of Mecosta county. At Mt. Pleasant water is found in gravel at a depth of 205 feet. Mr. Leverett informs me that much of the northern part of Isabella county is high moraine, flows being obtained only at the localities mentioned above, or on lowland tracts.

In a sand and gravel area extending southeast from Mecosta county into the southwestern corner of Isabella county, and thence south through Stanton as far as Belding in the northwestern part of Ionia, there are a number of flows where land is low among the moraine ridges. This area affords a good opportunity for further prospecting. At Mecosta, Remus, Millbrook, Blanchard, Edmore, Cedar Lake, Vestaburg, Stanton,

and Belding, artesian basins are tapped. At these localities the depth of water varies, being 35 feet at Millbrook, 30 feet at Blanchard, 40 feet at Stanton, where it is used for fire and domestic purposes, and 130 feet at Belding, where the water is found in sand. It will be noticed that the depth increases to to the south as far as our records show.

In the southern part of Newaygo county, in the basin of the Muskegon river, there are several artesian wells. At Fremont, section 5, T. 12 N., R. 14 W., Brunswick, Sitka, and Newaygo, there are flows, as well as a separate basin on the south side of the moraine at Grant, Bailey, Plumville, Grove and thence west and south along a tributary of the Grand river as far south as the latitude of Kent City. At Fremont water bearing beds are found at 18, 100 and 200 feet in the drift, the flow being about 15 feet above the surface for the deeper wells and 15 inches for the most shallow. The temperature is 51°. In the deepest wells the flow is given at 1,800 gallons per hour. The water is hard except in the well 18 feet deep. In Newaygo the depth to water varies from 30 to 44 feet. The wells both here and at Fremont are in the drift.

In the basin of the Muskegon river there are several flowing wells in the southern part of Osceola county at Reed City, Hersey, Evart, Sears, at Marion in the northeastern part of the county, and at McBain in the southwestern part of Missaukee. It is not impossible that flows would be obtained between these places, as well as in the environment of the places last mentioned. At Reed City flowing wells are found in interstratified beds of sand and gravel at a depth of 300 feet. Three miles southwest of the city the depth is only 100 feet. In the deeper wells the water is hard, becoming softer in the more shallow wells. At Marion there are only a few flowing wells out of a number of records that I have received. The depth at that place varies from 30 to 60 feet. McBain situated northwest of Marion has a flowing well at 30 feet, while another well having a depth of 140 feet rose to within 15 or 30 feet of the top.

In the highlands north and east of McBain I have not obtained the records of any flowing wells. In this region water is found at a depth of from 25 to 175 feet at Morley in Missaukee county; from 20 to 70 feet at Fletcher in the southeastern part of Kalkaska, at a depth of 200 feet at Grayling, 176 feet at Frederic, and 90 feet at Gaylord. Flowing wells will probably be found all the way down the AuSable river.

At Indian River there are numerous flowing wells, the basin extending along the south and west side of Burt Lake, north along the Sturgeon river past Topinabee, Mullets Lake, and thence to Cheboygan. West from Burt Lake flows have occasionally been found, and there are numerous wells at Harbor Springs, which is almost due west of Indian River. Mr. Daniel Foreman, a driller residing at Harbor Springs, informs me that flowing wells have been found for a distance of 26 miles east of that place.

At Indian River the depth to water varies from 93 to 189 feet. In two wells 108 and 142 feet deep, the head forces the water 20 feet above the surface, while another well 110 feet deep rises 35 feet above the ground, which is the greatest elevation given. Again in the well record having a depth of 175 feet, the water rises 30 feet above the surface. Not having the elevation of the wells it is impossible to arrive at any satisfactory conclusion relative to depth and head. In all the wells the water is hard and impregnated with iron. The temperature is given at 48° F. in four wells varying from 108 to 142 feet deep, and as 44° F. in one well

110 feet deep. The flow is given as 100 gallons per minute at 142 feet, 180 at 110 feet, and 200 at 112 feet; while in another lot the flow would average four barrels per minute in three wells having an average depth of 106, and three barrels per minute in four wells with an average depth of 135. Not until the elevation above tide is determined for some of the different wells, and the amount of flow actually gaged as given in Schlichter's paper can any reliable conclusions be arrived at concerning the relation of depth and head. Mr. G. P. Cowley has sent me the following record of strata passed through in one well there:—

Well at Indian River.	Feet.
Sand	40
Hardpan	7
Sand	12
Gravel	5
Sand	25
Clay	15
Gravel	5

In three other wells the amount of surface sand varies from 40 to 45 feet, with from 53 to 60 feet of clay overlying the gravel in which the water is found. At Topinabee there are two wells with a depth of 119 feet, the flow being in the drift. In one well the water will rise 11 feet above the surface, in another from six to eight feet. The temperature in the Sanitas deep well belonging to H. H. Pike's Sons is 48°. To Mr. Horace L. Pike I am indebted for an analysis of the water from this well, which was made by Prof. I. V. S. Stanislaus of Notre Dame University.

Physical examination showed:—

Color	none
Odor	none
Taste	perfect
Reaction	neutral

Chemical examination in parts per 1000.

Chlorine	.0145
Free ammonia	none
Nitrogen in nitrates	.0023
Total hardness	.0202
Permanent hardness	.0171
Organic and volatile matters (by loss)	.0182
Total solids	.1146

The inorganic constituents proved potassium, sodium, and magnesium bi-carbonates and chlorides, with sodium phosphate and calcium.

At Harbor Springs flows are found from 45 to 320 feet in depth as at Mr. E. Shay & Son's well. All the wells are said to be in the drift. In Mr. Shay's well the flow amounts to 100 gallons per minute, the temperature being 45° F. Mr. Lane has given an analysis of this well in Water Supply paper No. 31. Mrs. Chas. Roe writes me that flowing wells were first discovered there by driving piling 200 feet from shore for Roe & Co.'s steamboat dock. The flow was struck at a depth of 45 feet, and was of sufficient strength to lift heavy piles after being driven down.

Along the latitude of Harbor Springs and Indian River, artesian water has been struck at Rogers City on the shore of Lake Huron. Mr. F. C. Larke, president of the village council has sent me the following section of beds passed through:—

Well at Rogers City.	Feet.
Coarse gravel	10
Hardpan with streak of gravel	80
Limestone	21

In the basin contiguous to Lake Michigan and south of Harbor Springs, there are artesian basins all the way down to the Indiana state line. Adjacent to Grand Traverse bay and Pine Lake flows are found both at Boyne and Boyne Falls; near Bellaire, Williamsburg, South Boardman and Traverse City. In the little finger of the lower peninsula, forming Leelanaw county, there is a flowing well near Provement, and farther down the coast at Empire, Frankfort, Beulah, Thompsonville and Onekama. East of Onekama, in the basin of the Manistee river, there is an artesian basin at Yates and another around Fife Lake. However, just west of Fife Lake and around Summit City, water is found at a depth of 94 feet, gradually increasing to the south, until on the north side of the Manistee in section 4 of T. 24 N., R 10 W., water is found at a depth of 135 feet. In these wells water does not reach the surface. Likewise east of Yates at Wexford, it is 47 feet to water, near Farnsworth 127 feet, while in Antioch township, T. 23 N., R. 11 W., the depth varies from 60 to 128 feet. The area of non-flowing wells is continued on to the southeast where at Cadillac the depth varies from 125 to 225 feet to water.

Around Ludington flows are again struck. In Oceana county there are several separate areas of flowing wells near Hart, Elbridge, section 24 of T. 15 N., R. 17 W., Shelby, section 18 of T. 14 N., R. 17 W., Marshallville and Holstein.

Muskegon and Fruitport both have artesian wells, and in the valley of the Grand river we find flows at Eastmanville, Lamont, and Georgetown, 19 miles east of the shore of Lake Michigan.

Again adjacent to the lake at West Olive, Gibson, Hamilton on the Rabbit river, and at Ganges there are flowing wells, while at Casco, seven miles south of Ganges, it is 160 feet to water which does not reach the surface.

In Van Buren, Cass and Berrien counties, the civil divisions correspond to an enlarged artesian area. This region is rather heavily belted with moraines running parallel with Lake Michigan, and flowing wells are only found in the lower areas. In this territory flows have been obtained near South Haven, Lacota, Grand Junction, Geneva, Breedsville and Bangor in the basin of the Black river; around Watervliet, Hartford, Lake Cora, Paw Paw, and Keller in Van Buren county, in the basin of the Paw Paw; in Cass county there are a few flows near Marcellus, Penn, Pokagon and Dowagiac; while farther west in Berrien county there are artesian wells at Niles, Berrien Springs, Buchanan and New Troy.

Throughout this considerable extent of the lower peninsula, the depth to artesian water varies. At Boyne the depth to water-bearing gravel is 70 feet, the temperature being 50°. At Bellaire the water is also found in the drift at the depth of 100 feet. The capacity is 4,000 gallons per day, and is used in the city water supply.

At Williamsburg, Mr. John H. Russell of Detroit, obtained flows at 45, 82½, and 87 feet, the water coming from interstratified gravel beds in the till. Most of the flows there occur at a depth of from 58 to 65 feet, the average depth being 61 feet. The water rises from 10 to 20 feet above the surface, the average elevation for six wells being 14 feet. Mr. Russell gives the temperature as 43° for one well 87 feet deep, and 45.5° for another well 82½ feet deep. In two other wells 58 and 60 feet deep the temperature is given as 42°, while another well 64 feet deep is 45°. Mr. Emery Rose has sent me the following section of beds passed through there:—

Emery Rose well at Williamsburg.	Feet.
Sand	15
Blue clay	20
Sand	2
Blue clay	22
	60

I am also indebted to Mr. Russell for an analysis of the water from his well 45 feet deep which was made by John E. Clark:—

	Grains per U. S. gallon.
Sodium chloride	.2571
Sodium sulphate	.0085
Potassium sulphate	.0431
Magnesium sulphate	.5051
Magnesium carbonate	1.6671
Calcic carbonate	6.8410
Ferric oxide	.5004
Aluminic oxide	.3169
Silicic acid	.4907
Lithia carbonate (present but not estimated.)	
Organic matter	trace
	10.6299

Detroit College of Medicine, March 6th, 1893.

At Provemont there is an artesian well 780 feet down which was drilled about 1853. The flow amounts to one barrel per minute. I am obliged to Mrs. Florence M. Whitfield for an analysis of this water, which is as follows:—

Analysis of Whitfield well at Provemont.	Grains per U. S. gallon.
Sulphate magnesia	14.295
Sulphate alumina	4.172
Sulphate lime	6.005
Chloride sodium	1.240
Carbonate silica	1.96
Hydroxide of iron	.269
Total	27.941

	Cubic inches.
Sulphuretted hydrogen	10.09
Carbonic acid gas	29.14
Total	39.23

At Empire the flow is found in gravel at a depth of 60 feet.

East of Frankfort there are several flowing wells at Beulah, near the head of Crystal lake. The depth of water varies from 97 to 163 feet, the amount of flow in one well is stated to be 270 barrels per day, in another 300 barrels, the deeper wells having the greater head. Mr. H. T. Smith has sent me the following section of his well:—

	Feet.
Gravel and sand	10
Blue clay	20
Sand, solid clay and gravel	67

At Onekama, the shore of Portage lake is surrounded by a flat 20 to 40 rods broad, on which a flow may be obtained by driving a pipe, beginning at 15 to 20 feet with a one-half inch stream, and increasing in volume, in head, for greater depth. Mr. Davis' wells at 60 to 100 feet have a very strong flow, throwing a stream horizontally 10 to 20 feet.

At Hart the depth of water is 173 feet with head sufficient to throw the water 20 feet above the surface. Mr. Lane has obtained the following section of beds passed through at the Potato Starch factory situated there:—

Hart Potato starch factory well.	Feet.
Clay till	43
Water gravel	1
Plastic clay	129
Cavity	1
Total	174

The temperature of the water as determined by Mr. Lane with a standard self-registering thermometer was 49.5°, August 23, 1902.

Elbridge, situated 6½ miles east of Hart has a flow at a depth of 93 feet, the water rising 20 feet above the ground.

Mr. Isaac Timmons sends me the following sections of beds passed through there:—

Elbridge.	Feet
Sandy soil	30
Clay, into water-bearing gravel	63
	93

Southeast of Elbridge in section 25 of T. 15 N., R. 17 W., Mr. Amos Rellinger has the following log:—

	Feet.
Sand	24
Gravel	2
Clay, water-bearing sand	89
	115

In Muskegon county, according to C. D. McClouth, flowing wells are quite common along the shore, ranging in depth from 35 feet at Montague to some 250 feet at the south line of the county. Around Fruitport wells have a head of about 30 feet above the lake, or six feet above the ground.

In the southwestern portion of the lower peninsula, the variation in conditions producing flowing wells are very considerable. Six and one-half miles southeast of South Haven an artesian well has a depth of 228 feet, with the following section:—

Well near South Haven.	Feet.
Sand	20
Clay	170
Soft rock (Coldwater shale)	38
	228

Near Watervliet there are two wells with a depth of 45 and 50 feet, the flow being in sand and gravel, while another well in the drift is 89 feet in depth. In all these wells the flow is 10 feet above the surface. In the wells 50 and 89 feet deep the temperature is given as 50°. The water is hard, in common with the most of the wells in the Pleistocene. Near Hartford I have the records of two wells in the drift which are 44 and 58 feet deep, the water rising seven and ten feet above the surface. At Paw Paw flows are found in the lower levels of the Paw Paw valley at depths variously given as from 40 to 100 feet.

For artesian conditions in Cass county the reader is referred to the special report on that territory.

CHAPTER II.

SPRINGS AND NON-FLOWING WELLS.

At numerous localities in the lower peninsula of Michigan water horizons reach the surface. A large number come from gravel beds in the drift. In other cases where beaches have been left during the later stages of the Pleistocene or lacustrine epoch, small surface springs flow from the base of the beach. I suspect that in rare cases springs will be found to indicate interglacial deposits. The valley of the AuSable and the high cliffs around Frankfort and Newaygo may expose such formations. Where the margin of overwash sand and gravel beds lie above the till, fine springs are frequently found. When these areas have been indicated it will be possible to locate springs with quite a reasonable degree of certainty. Bed rock is so infrequently exposed in the lower peninsula as to make it a small factor in water supplies of this character. However, in

the Traverse formation near Alpena, I have seen quasi springs in sink holes where the subsurface drainage has eroded away the overlying limestone. Again as at Barron lake the water is derived from springs which serve as a water supply for Niles. In this connection it might be well to gage streams issuing from inland lakes, with a view to utilizing such water for city and town use. The water supply of Adrian, which is a source of serious consideration, might be obtained from lakes in the northwestern part of Lenawee county, but I doubt if the supply would be in the least adequate. In most cases our inland lakes are either drying up, or are represented by beds of muck. In this chapter it is intended to give all the information obtained relating to the geographical distribution of springs, but it is not presumed that the information is complete. Analyses of 12 springs have been obtained. Part of these have already been given in Mr. Alfred C. Lane's Water Supply report No. 31. The rest will be given at the end of this chapter.

In the valley of the Huron river above Ann Arbor there are a number of fine springs near Delhi in the same area. In the valley of the Paw Paw there is a spring southeast of Benton Harbor and another near Hartford in Van Buren county. In Jackson county there are a number of springs in Springport township, T. 1 S., R. 3 W., in the drainage basin of the Grand river. This area is indicated as covered with interlobate sand and gravel in plate 2 of Water Supply paper No. 30. In the same county springs have also been found near Brooklyn and Napoleon in the southeastern part of the county.

In Wayne county there is a spring at Plymouth in the northwestern part of the county. At Dorr and Moline in the basin of the Rabbit river springs are found in a region covered with sand and gravel. This is also true of Anderson in the southwestern part of Livingston county. In the eastern part of Oakland county there are springs near Thomas, Pontiac, and Troy, as well as in Macomb county near Mt. Clemens, and at Fraser in the southern part of the county.

In the basin of the Grand River there are similar water supplies at Spring Lake, Nunica, Crockery, Eastmanville, Grand Rapids, Bowen, Ionia and Lansing. This region is mostly covered with sand and gravel. Farther east in about the same latitude they are found at Owosso and St. Clair adjacent to the St. Clair river. In the northern part of Gratiot county, in the basin of the Pine river, there are springs in section 23 of T. 12 N., R. 4 W., near Elwell, Alma, St. Louis, and at Midland, where the Pine unites with the Tittabawassee river. In Oceana county there is a spring at Hesperia in the valley of the White river. Thence east at Big Rapids in the valley of the Muskegon we obtain similar flows. In Bay county springs are often found at the foot of beaches which were deposited in lake basins during the glacial retreat. The flow is quite limited. In the basin of the Muskegon river in Osceola county there are numerous springs in LeRoy township, T. 19 N., R. 10 W.; and near Marion in the northeastern part of the county. Also at Tustin, near the headwaters of the Manistee, springs are found. In Hatton township, T. 18 N., R. 4 W., there are similar flows along the headwaters of the Tobacco river. Likewise in the valley of the Tittabawassee near Highwood, springs are abundant. In the valley of the Manistee there are similar water supplies at Manistee, in Springville township, T. 23 N., R. 12 W., east of Beulah three miles, Manton in the northeastern part of the same county,

and at Cadillac. In section 18, T. 21 N., R. 1 W., and near Butman in the northwestern part of Gladwin county springs also occur.

At Frankfort and around the shores of Crystal lake there are springs at rather numerous locations. In Oscoda county there are springs at Luzerne and Mio in the valley of the AuSable river.

In the area adjacent to Grand Traverse bay and Lake Michigan, similar water supplies have been located on the eastern shore of Torch lake in T. 30 N., R. 8 W., near Norwood, in Jordan township, T. 31 N., R. 6. W., as well as at Levering. At Topinabee there is a spring of which an analysis will be given further on. At the headwaters of the Sturgeon river there are also a number northeast of Gaylord. In the basin of the Thunder Bay river, springs are also found at Big Rock, Atlanta and Alpena. While this list is not in any way complete it will serve to give some idea of the very general distribution of this source of water supply in the lower peninsula of Michigan.

Analyses of Springs.

Benton Harbor.

Four of these analyses have already been printed in Water Supply No. 31. The additional records here given were made by Prof. E. G. Smith of Beloit College, Wisconsin. They belong to the same group as the Eastman springs.

"Bimini" Benton Harbor.	Gallon of 231 cubic inches. Grains.
Potassium sulphate	0.052
Sodium sulphate	0.524
Sodium chloride	0.104
Sodium phosphate	0.017
Sodium borate	trace
Sodium bi-carbonate	0.262
Magnesium bi-carbonate	3.557
Calcium bi-carbonate	7.484
Iron bi-carbonate	0.075
Alumina	0.034
Silica	0.542
Total	12.651

"Winans," Benton Harbor.	Gallon of 231 cubic inches. Grains.
Potassium sulphate	0.104
Sodium sulphate	0.314
Sodium chloride	0.093
Sodium phosphate	0.023
Magnesium sulphate	0.419
Magnesium bi-carbonate	3.126
Calcium bi-carbonate	5.564
Iron bi-carbonate	0.039
Alumina	0.058
Silica	0.402
Total	10.142

"Golden Fountain," Benton Harbor.	Gallon of 231 cubic inches. Grains.
Potassium sulphate	0.116
Sodium sulphate	0.262
Sodium phosphate	0.040
Sodium chloride	0.093
Magnesium sulphate	0.180
Magnesium bi-carbonate	3.213
Calcium bi-carbonate	8.206
Iron bi-carbonate	0.384
Manganese bi-carbonate	trace
Alumina	0.017
Silica	0.408
Total	12.919

"Psyche," Benton Harbor.	Gallon of 231 cubic inches. Grains.
Potassium sulphate	0.104
Sodium sulphate	0.507
Sodium chloride	0.016
Sodium phosphate	0.017
Magnesium bi-carbonate	2.257
Calcium bi-carbonate	6.604
Iron bi-carbonate	0.025
Alumina	0.058
Silica	0.513
Total	10.101

Analysis of water from a surface spring at Spring Lake, Ottawa county, Michigan. The color is clear; taste, saline; temperature, about 60° F. It is the property of E. C. Dyer of Chicago, but I obtained my information from Geo. H. Hammond of Spring Lake village.

Spring Lake.	Grains per gallon.
Potassium chloride	4.2880
Sodium chloride	405.5330
Calcium chloride	113.4200
Magnesium chloride	36.2000
Sodium bi-carbonate	0.9537
Calcium bi-carbonate	0.1808
Iron bi-carbonate	0.0060
Magnesium bi-carbonate	0.0640
Manganese bi-carbonate	0.0647
Magnesium bromide	2.1700
Sodium sulphate	46.7000
Silica	0.5030
Alumina	traces
Total fixed residue	629.3684

C. Gilbert Wheeler, Professor of Chemistry, University of Chicago.

Prof. I. V. S. Stanislaus of the University of Notre Dame has made an analysis of a spring belonging to H. H. Pike's Sons of Topinabee.

Topinabee Hill Springs. Physical examination showed:—

Color	none
Odor	none
Taste	soft
Reaction	neutral

Chemical examination:—

	Parts per 1,000.
Chlorine	.0155
Nitrogen and nitrates	.0037
Total hardness	.0210
Permanent hardness	.0180
Organic and volatile matters (by loss)	.0190
Total solids	.2410

The inorganic constituents contained potassium, sodium, calcium, magnesium bi-carbonates and chlorides, in small quantities.

NON-FLOWING WELLS.

In this report it is not intended to give any detailed account of ground waters which do not reach the surface. For those who are interested in geological work in the lower peninsula, however, it has been thought well to print all the sections which have not yet been published, inasmuch as they either fill in gaps of territory not heretofore covered or correlate sections already printed. Primarily these sections are intended for reference to those engaged in geological work in the lower peninsula or adjacent states.

To Mr. T. B. Pettit of Benzonia, Mich., I am indebted for the following log, which is in section 27, T. 26 N., R. 15 W.:—

Benzonia well.	Feet.
Sandy loam	4
Clay	19
Sand and gravel	50
Total	73

Mr. F. R. Deckrow, in a well put down for Chas. Richardson on section 16 of T. 25 N., R. 2 W., went through 90 feet of blue clay, the water being found in a gravel bed underneath. The water rises within 22 feet of the surface. In another well 186 feet deep, for Jacob Karner, T. 28 N., R. 4 W., the first 10 feet was of clay loam, the balance being sand. A third well made by the same driller for Mr. A. House in section 17, T. 28 N., R. 3 W., has a depth of 200 feet. The first 10 feet was sandy loam, the balance being sand and gravel. The water raised 10 feet.

At Highwood water is found at a depth of from 8 to 20 feet in gravel below the clay, the water in some wells rising to within 18 inches of the surface. To Mr. W. G. Hay of West Saginaw, Michigan, I am indebted

for the record of the following holes which were put down by Mr. A. J. Utter while prospecting for coal in the vicinity of Highwood, Gladwin county. In no case was bed rock reached. In well No. 3 the water rose within 18 inches of the surface.

Report on Wells at Highwood.

Well No. 1.

N. E. ¼ of S. E. ¼, Section 26, Town 18 N., R. 1 East.

1 ft. Surface.
2 ft. Sand.
37 ft. Putty clay.
13 ft. Hardpan.
2 ft. Shell rock.
27 ft. Sand; coarse river sand, indicating a wash out, or where the bed rock dips down to a great depth.

82 ft.

Well No. 2.

S. E. ¼ of S. E. ¼, Section 27, T. 18 N., R. 1 East.

1 ft. Muck.
3 ft. Sand.
35 ft. Putty clay.
16 ft. Hardpan.
12 ft. Putty clay.
5 ft. Hardpan.
20 ft. Putty clay.
8 ft. Hardpan.
16 ft. Putty clay.
5 ft. Hardpan.
25 ft. Red marl.
31 ft. Sand (wash out).

176 ft. Total.

Well No. 3.

N. W. ¼ of N. E. ¼, Section 3, Town 17 N., R. 1 East.

32 ft. Clay.
9 ft. Hardpan.
12 ft. Putty clay.
2 ft. Hardpan.
39 ft. Quicksand (not through sand).

94 ft. Water to within 18 inches of the surface.

Well No. 4.

S. E. ¼ of N. E. ¼, Section 34, Town 18 N., R. 1 East.

1 ft. Muck.
2 ft. Quicksand.
37 ft. Putty clay.
10 ft. Hardpan.
16 ft. Hard black gravel clay.
14 ft. Hard black gravel clay.
32 ft. Hard black gravel clay.
14 ft. Hardpan.
35 ft. Red marl, streaked with gray.
1 ft. Sand.

162 ft.

Well No. 5.

S. E. ¼ of S. E. ¼ of Section 13, T. 18 N., R. 1 W.

1 ft. Muck.
1 ft. Sand.
1½ ft. Marl.
2 ft. Sand.
12 ft. Putty clay.
5 ft. Hardpan.
15 ft. Putty clay.
8 ft. Hardpan.
11 ft. Putty clay.
10 ft. Hardpan.
22 ft. Putty clay.
4 ft. Sand and gravel—good vein of water in this gravel.
9 ft. Hardpan.
40 ft. Gravelly clay.
20 ft. Putty clay.
33 ft. Hardpan.
38 ft. Quicksand.

232½ ft. (Still 12 ft. of sand.)

Mr. John Sisson of Imlay City has sent the following log of his well. It is situated in Section 33 of T. 8 N., R. 12 E.

Well near Imlay City.	Feet.
Clay	4
Fine water sand	50
Quicksand	6
Coarse gravel	1
Blue putty clay	19
Shale rock? (Coldwater)	73
	153

The Antrim Iron Co. at Mancelona has a well from 250 to 300 feet deep, the depth to principal source of water being 65 to 70 feet. Sand and gravel formed the greater part of the strata passed through. A bed of clay 10 to 20 feet thick was struck at 160 to 215 feet from the surface.

This well apparently did not reach the rock. To the Antrim Iron Co. I am indebted for the following analysis:—

Mancelona. Antrim Iron Co.	Grains per U. S. gallons.
Silica	.5240
Oxides iron and alumina	.1458
Carbonate of lime	7.4646
Carbonate of magnesia	2.4493
Sulphate of lime	.5248
Sodium and potassium chlorides	trace
Sodium and potassium carbonate	.3218
Total solids	11.4303

The Michigan Sulphate Fibre Co. of Port Huron has very obligingly sent me through their manager, Mr. O. L. E. Weber, the following sections, analysis and data. I quote from Mr. Weber's letter and report:—

"Well No. 1 was drilled in the spring of 1898, our object being a search for either gas or oil for fuel purposes. Six-inch and eight-inch pipe was used to the slate and smaller pipe continued down. At a depth of 266 to 267 feet from the surface we encountered quite a strong flow of gas, pressure of which ran up to over 75 lbs. gauge, and the entire pressure was blown off in about two days through a seven-inch pipe and has not recovered since. Analysis of the same you will find as the last item in the description of these wells. At 575 feet we began to get traces of salt and the well was discontinued at 600 feet. The following is the data of the material passed through as given by Mr. A. Morrison, the well driller.

Wells 2, 3, 4, and 5 were drilled in the fall of the year 1900, our object this time being a search for a supply of water for our mill. The following is a description of the four wells:—

Data of material gone through in well No. 1, Port Huron.

	Feet.
From surface to 78 feet, drift sand	78
From 78 feet to 102 feet, blue clay	24
From 102 feet to 107 feet, gravel drift clay with pebbles	5
From 107 feet to 187 feet, slate	80
From 187 feet to 215 feet, top lime rock	28
From 215 feet to 266 feet, soap stone	51
From 266 feet to 311 feet, lime rock	45
From (266 feet to 267 feet), gas	
From 311 feet to 319 feet, soap stone	8
From 319 feet to 321 feet, lime rock	2
From (319 feet to 321 feet), gas	
From 321 feet to 415 feet, soap stone	94
From 415 feet to 417 feet, middle lime	2
From 417 feet to 482 feet, lower soap	65
From 482 feet to 600 feet, lower lime	118
	600

Well No. 2, Port Huron.

From surface to 48 feet, sand and drift.
From 48 feet to 64 feet, blue clay.
From 64 feet to 72 feet, coarse gravel.

Well No. 3, Port Huron.

From surface to 46 feet, sand or drift.
From 46 feet to 62 feet, blue clay.
From 62 feet to 70 feet, gravel.
From 70 feet to 101 feet, blue clay and 1 foot of black sand.
From 101 feet to 391 feet, black shale.
From 391 feet to 491 feet, soap stone.
From 491 feet to 521 feet, lime rock with strong flow of gas.
From 521 feet to 651 feet, soap stone.
From 651 feet to 728 feet, lime rock with indications of petroleum.

This well showed very little water on top of bed rock. Well was cased with 46 feet of wooden conductor, 10 inches diameter on the inside. One hundred and four feet of eight-inch pipe to bed rock.

Well No. 4, Port Huron.

From surface to 48 feet, sand or drift.
From 48 feet to 65 feet, blue clay.
From 65 feet to 74 feet, gravel with large supply of water.

Well No. 5, Port Huron.

From surface to 48 feet, sand or drift.
From 48 feet to 65 feet, blue clay.
From 65 feet to 76 feet, gravel.

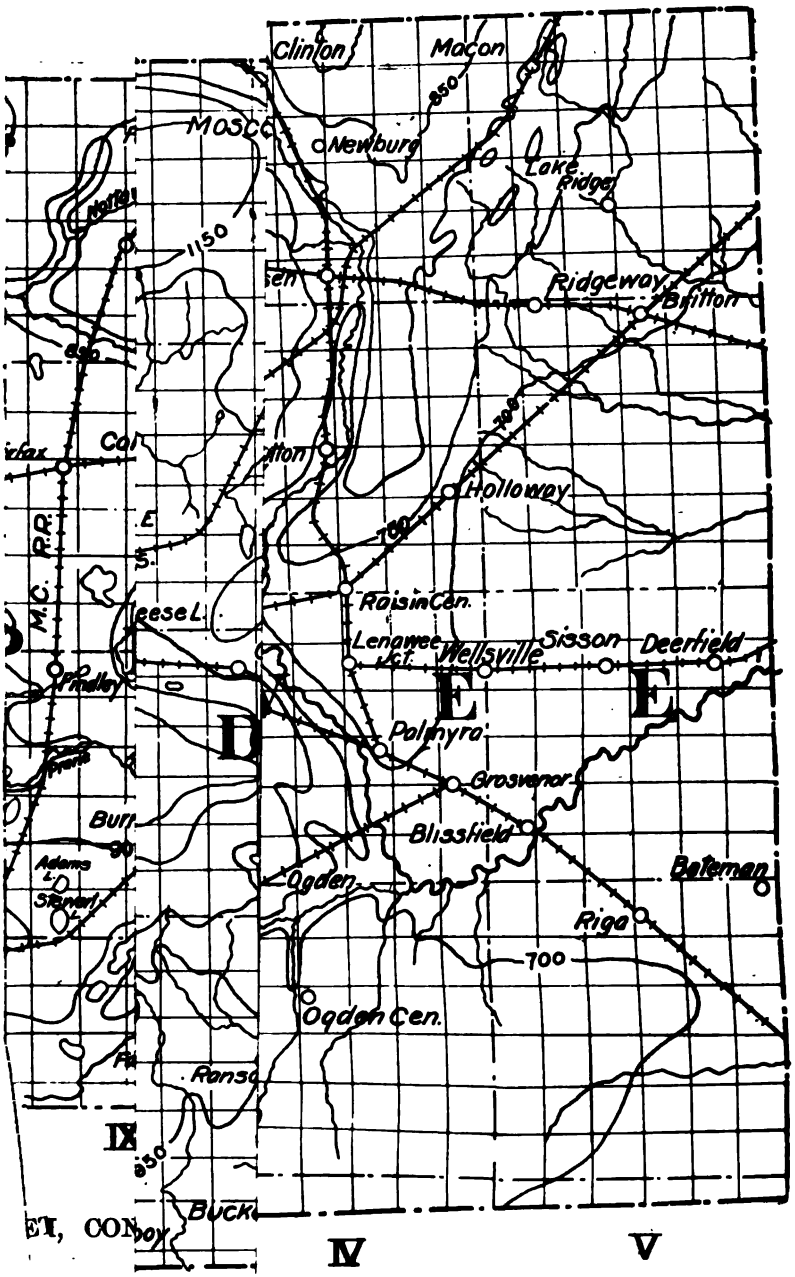
Wells 2, 4 and 5 are cased with a wooden conductor 46 feet deep, 10 inches inside diameter and continued with 10-inch iron pipe to the depth of the well excepting No. 5 which has a 12-inch instead of a 10-inch pipe.

The wells are stopped at the bottom with wooden plugs, each with about 400 ½-inch holes extending up from the bottom of the pipe about seven feet.

Water in the wells rose to within about 19 feet of the surface and at the time observations were taken this was about one foot below the surface of Black river. The wells were pumped 10 hours a day for about two weeks with the idea of freeing the water from the iron held in suspension, but it did not free it to any appreciable extent. The following is an analysis of the water:—

Suspended matter 66.00 parts per million, mostly clay carrying iron. The filtrate analyzed as follows:—

	Parts per million.
Silica ($Si O_2$)	27.40
Iron and alumina (Fe_2O_3 Al_2O_3)	1.15
Lime (Ca O)	128.80
Magnesia (Mg O)	33.85


Clinton
Macon
Newburg
Lake Ridge
Ridgeway
Britton
Holloway
Raisin Cen.
Lenawee Jct.
Wellsville
Sisson
Deerfield
Palmyra
Grosvenor
Blissfield
Bateman
Ogden
Riga
Ogden Cen.
M.C. R.R.
Findley
Adams L.
Stewart L.
Burr
Buck
850
1150
700
III
IV
V

The following is an analysis of gas from well No. 1:—

Marsh gas (Methane)	88.64%
Hydrogen	2.27%
Carbon monoxide	0.20%
Nitrogen	8.89%
Total	100.00%

CHAPTER III.

TOPOGRAPHY AND WATER POWER OF LENAWEE, HILLSDALE, BRANCH, ST. JOSEPH AND CASS COUNTIES.

In the descriptive portion which pertains to this chapter, the elevations are given above tide. By this is meant the elevation above the average sea level height of New York bay. This is the zero which has been adopted by the U. S. Government, and all topographic elevations are stated as so many feet or fractional parts of a foot above this datum or zero. In the contour lines which are represented on the maps forming part of this report, each line is intended to represent the same constant elevation above sea level, or above tide as it is usually stated. This is generally abbreviated A. T. In this connection I cannot do better than quote Mr. Alfred C. Lane as to the proper significance of contours.[1] "As we have said, in 1896, Lake Huron had been retreating. Imagine the process suddenly reversed, and the lake suddenly raised 10 feet and the new shore line marked upon the map. Suppose the lake raised 10 feet more, and the resulting shore line marked upon the county. Such lines would be called contour lines and all points of a given contour line are obviously at the same level above the lake." In the maps presented in this report the contour lines are represented at intervals of 50 feet of vertical elevation, and are only approximately located, but one line of elevations having been taken through each township. In the map of Lenawee county it will be observed that the lowest line is marked 700 A. T. This means that if Lake Erie were to rise 130 feet from its present elevation of about 570 feet above tide the shore line of the lake would wash the hills and plains and form inlets up the valleys as approximately indicated by the 700-foot line A. T. The same would be true of each successive line of greater elevation. In the different intervals islands would appear. These imaginary islands are represented by contour lines which entirely enclose a certain amount of land. Such areas will be observed northeast of Tecumseh and at Prospect Hill in the northwestern part of Lenawee county. It will be readily observed that there is a great advantage in having a common base as a reference plane from which to estimate all points of elevation, and in this report it may be understood that sea level in New York harbor furnishes such a base. High water of 1838 in the great lakes is supposed to be 584.34 feet above it (i. e., 584.34 A. T.).

[1]Michigan Geological Survey, Vol. VII, part 2, P. 42.

Highest Elevations.

Within this area the highest elevation is at Bunday hill, situated in section 8 of Somerset township, Hillsdale county, T. 5 S., R. 1 W., the altitude being 1,284 feet above tide as given in the report of the U. S. Lake Survey. At another station in the northwest quarter of section 29, T. 6 S., R. 1 W., the elevation is 1,247 A. T. In the intervening area about the lowest elevation is near Jerome Station where the surface drops to 1,105 A. T. This axis of elevation runs north and south, very nearly one mile east of the line between ranges 1 and 2 west. The northern limit is Bunday hills, while southward the elevation at Pittsford geodetic station is 1,149 A. T., the depot at Pittsford being 1,087 A. T. These elevations form part of a morainal accumulation which was deposited by the Huron-Erie glacier lobe. This area of greatest elevation forms the divide between the waters of Lake Erie and Lake Michigan and is approximately one-third of the distance across the state going west.

Lenawee County Moraine.

On the east side of the Hillsdale watershed the elevation falls quite rapidly to the east, in Lenawee county. The highest elevation within this county is Prospect hill, which is about 100 feet lower than Bunday hill, or 1,184 feet A. T. Where the Raisin river enters Monroe county the altitude is less than 650 A. T., making the extremes of elevation 634 feet. Prospect hill is located in section 13 of T. 5 S., R. 1 E. The Huron-Erie glacier lobe deposited in its retreat a great amount of morainal accumulation in the northwestern part of this county including the Prospect hill area, the principal moraine leading from Hudson northeast in an irregular line to the northeastern corner of section 5, T. 5 S., R. 3 E.

Inside of this area the greater part of the lakes in Lenawee county may be found. Posey lake, northeast of Hudson, is 933 A. T. This has an outlet into the Tiffin river. Devil's lake is 1,051 feet A. T. Pickerel lake in the northeast quarter of section 14, T. 5 S., R. 1 E., is 971 feet A. T., being very nearly on the same elevation as Deep lake, which is on the other side of Prospect hill. Lake Dody and Lake Washington, situated southeast of Cambridge in T. 5 S., R. 2 E., both have an elevation of 996 A. T. Goose lake, southeast of Woodstock, is about 1,005 A. T.

Later Huron-Erie Moraines.

East of this principal moraine last described, there are three small inlying moraines, deposited by the same Huron-Erie glacier lobe. As will be seen on the map, they trend southwest, ending at the north, west of Tecumseh, and at the south, northwest of Adrian. For the most part they are in townships 5 and 6 S., and R. 3 E. The elevation of the most westerly one reaches a height of 860 A. T. The extension of this moraine to the south causes Wolf creek to form a loop in the same direction, before emptying into the Raisin river at Adrian.

Moraine West of Hillsdale.

West of Hillsdale there is another very considerable area of glacial accumulation which has a northwesterly trend, the northern limit being near the road from Jonesville to Quincy, the southeastern end is about

three miles west of Pittsford. On both flanks there is a chain of lakes and ponds which either form areas due to the unequal amount of glacial accumulation, the melting of buried or surface ice masses, or glacial drainage valleys which have become filled up by glacial or post-glacial erosion, the lakes representing glacial mill ponds, as it were. Within this area the highest elevation of which I have any knowledge of, is the station of the U. S. Lake Survey. This is situated in the west half of section 27 just southwest of Hillsdale. The elevation is 1,238 feet A. T. The elevation of the Lake Shore depot at Hillsdale is 1,085 A. T. On the road leading south from Hillsdale and two miles west of the range line, the highest elevation is 1,219 feet A. T. This is four-tenths of a mile north of the east quarter post of section 10. Thence south the elevation drops to 1,042 at Cubb lake in section 34, T. 7 S., R. 3 W. This forms the southern extremity of the same chain of which Sand lake is the northern link. Cubb lake is near the headwaters of one of the feeders to St. Joseph of the Maumee. Camden, which is situated on another tributary of the same stream, is in the southwestern part of the county and is approximately 988 feet A. T. The main branch of the St. Joseph of the Maumee is in the southeastern part of Hillsdale county. Near the northeast corner of section 28, T. 7 S., R. 1 W., the elevation is 926 A. T. A feeder which starts about one-half mile south of Pittsford has an elevation of 1,025 A. T. Laird creek, another branch of the same stream, has an elevation of 985 A. T., just north of the east quarter post of section 16, T. 8 S., R. 2 W. Burt creek, another feeder, is 905 feet A. T., a few feet east of the northeast corner of section 23, T. 8 S., R. 2 W. Where this creek heads in Bird lake the elevation is 1,040 A. T.

Moraine at Reading.

Another deposit of morainal accumulations is west of the Hillsdale moraine. The main trend is north and south of Reading. At the Lake Survey station in the northwest quarter of section 24, T. 7 S., R. 4 W., the elevation is 1,208 A. T. Four and one-half miles south the elevation at Camden is 988 A. T. as already given. To the north the elevation drops to 1,081 A. T. within six miles.

Moraine North of Hillsdale.

North of Hillsdale there is a knoll of morainic material which accumulated on the southern border of the Saginaw shoulder. In the southeastern quarter of section 29, T. 5 S., R. 3 W., the elevation is 1,150 A. T. The area is quite circumscribed.

Moraine in Western Branch County.

On the western side of the Hillsdale watershed in Branch county, there are several irregular areas of morainic deposition. The ice retreating to the northwest deposited in the western part of Branch county a moraine which leads northeast, west of Bronson, within two miles west of Union City. From there the course southwest is about parallel with the St. Joseph river. At the station of the U. S. Lake Survey in the southwest quarter of section 16, T. 7 S., R. 8 W., the elevation is 997 A. T.; at the northeast corner of section 33, T. 5 S., R. 7 W., the altitude has fallen to

975 feet. Matteson lake, situated within this area, has an elevation of 889 feet. The drainage is all westward into the St. Joseph river.

Lakes in Central Branch County.

After the deposition of this moraine there was a period of recession, during which time the drainage was parallel with that of the moraine last deposited, and in front of the retreating ice mass. This may account for the chain of lakes which extends northeast of Bronson towards Girard. The lakes appear to be formed of ice drainage outlets which were locally dammed up by either glacial or post-glacial material.

To the south and east of Coldwater there are several lakes within the limits of the Huron-Erie lobe. The Huron-Erie glacial lobe entered Michigan in the southeastern part of Branch county, forming a scattered, irregular moraine south of Quincy. North of Quincy the deposits are to be referred to as the Saginaw shoulder, which extends as far west as Coldwater, thence east to Jonesville and northeast to Mosherville in Hillsdale county.

Lakes in Southeastern Branch County.

Marble lake, situated between the Saginaw shoulder and Huron-Erie glacier, has an elevation of about 1,000 A. T. Coldwater lake is 950 feet above tide. California P. O., which is situated on the Huron-Erie lobe, is about 1,031 feet A. T. The highest elevation which has been determined on the Saginaw shoulder in the northeast part of Branch county, is in the southwest quarter of section 8, T. 6 S., R. 5 W. The station of the Lake Survey situated there has an elevation of 1,060 A. T.

Glacial Drainage.

Mr. Leverett informs me that as the great ice mass retreated north from Branch county the united drainage from the Michigan lobe on the west, the Saginaw shoulder which had not yet reached the form of a lobe, in the center, and the Huron-Erie lobe on the east, poured their united drainage down what is now the valley of the St. Joseph river. At that time it must have presented the appearance of a great glacial Amazon, the united waters laden with sediment, forming a stream many times greater in volume than the present river.

Sturgis Moraine.

St. Joseph county has a fine, well marked moraine in the southern portion, which Mr. Leverett has designated the Sturgis moraine. On the west it almost reaches the road which runs southwest from Centerville to Constantine reaching into section 16, T. 7 S., R. 11 W. From there the main axis of the moraine trends east and south of Burr Oak. Near the east quarter post of section 18, T. 7 S., R. 10 W., and just south of the northeast corner of section 19, in the same township and range, the elevation is 942 feet A. T. North and south from here the elevation falls rapidly. To the north, the east quarter post of section 30, T. 6 S., R. 10 W., is 830 A. T. South the descent is even more abrupt. In the creek which crosses the line, four-tenths of a mile north of the east quarter

post of section 31, T. 7 S., R. 10 W., the elevation is 823 feet A. T. This creek runs in a valley 61 feet high on the south side and 70 feet high going north, draining into Klinger's lake, and thence on into the Fawn river. Where the U. S. Lake Survey Station was situated in the northeast quarter of section 22, T. 7 S., R. 10 W., the elevation is 1,037 feet A. T. This is the highest point that I know of either on this moraine or in St. Joseph county. East of here, where the moraine is crossed by the G. R. & I. R. R., the greatest surface elevation is 960 feet A. T. This is 2¾ miles north of Sturgis. Sweet lake, on the south side of the moraine, and east of Sturgis, is 895 feet A. T.

Topography in St. Joseph County.

West of Sturgis the country is a plain, gently sloping to the west. In the valley of the St. Joseph river the country is level going from Nottawa to Mendon, Leonidas and Colon, the same topography being found between Three Rivers, Moorepark and Parkville. South of the St. Joseph river on the road leading from Parkville to Centerville, the land is rolling with undrained hollows. The east side of the St. Joseph river valley is level as far as White Pigeon and two miles east of there.

Interlobate Moraine.

In the western part of St. Joseph county and the eastern part of Cass there is a pronounced interlobate moraine. Going south from Vandalia the crest of this moraine is a well marked ridge trending east and west and having an extreme elevation of 977 feet A. T. This is one-tenth of a mile north of the east quarter post of section 28, T. 7 S., R. 14 W. One mile north from here the descent is 100 feet. To the south the elevation drops 117 feet in 1½ miles. Where the U. S. Lake Survey station was situated in the northeast quarter of section 27, T. 7 S., R. 14 W., the elevation is 1,010 feet A. T. In the southeastern part of T. 8 S., R. 13 W., the top of the moraine leads southeast, being 903 feet high in the southeast quarter of section 33, T. 7 S., R. 13 W.

In the semi-morainic area of this interlobate moraine the main trend is towards the northeast. At Jones the elevation is 921 feet A. T., the great mass of the moraine increasing in elevation northward. Northwest of Jones, Bald hill is 1,070 feet A. T. Another hill situated about three-tenths of a mile south and one-half mile west of the east quarter post of section 16, T 6 S., R. 13 W., has an elevation of 1,115 feet, which is probably the highest elevation in Cass county. This pronounced interlobate moraine is continued northeast into St. Joseph county. In the north half of section 33, T. 6 S., R. 12 W., there is a knoll having an elevation of 1,011 feet. North from here the descent into the drainage valley of Rock creek is quite rapid. Fabius, situated on the southern side of this interlobate area, has an altitude of 896 feet. Going north from Fabius the topography is hilly, many lakes being imprisoned in the moraine. Forming a pronounced ridge on top of this elevated moranic area is a hill range trending southwest through sections 6, 5 and 4, of T. 6 S., R. 12 W., and sections 33, 34 and 26 of T. 5 S., R. 12 W. Within this area the elevation is above the 950 foot contour line, culminating at a height of 1,011 feet A. T. The topography has much of the appearance of one moraine being built on top of another. This may be due to a readvance of the ice.

Rock creek, which bounds this interlobate moraine area on the north has an elevation of 825 feet at Howardsville and 839 feet on the road leading south from Marcellus. This creek meanders through a rolling country, and may have drained the front of the ice during its subsequent retreat.

Lakes of the Interlobate Moraine.

There are numerous lakes in the area of this interlobate moraine. Lake Baldwin and Long lake are situated in front of the morainic deposit in the southeastern part of Cass county, and are long, crooked lakes which have the appearance of drainage channels from off the ice, which were later obstructed by glacial or post-glacial drainage. In sections 21, 22, 23, 24, and 13, T. 7 S., R. 14 W., there is a chain of lakes draining into Christian creek. The most important of these are Curtis, Day, Sharps, and Clear lakes. The lakes are within the moraine and may have originated by the melting of ice masses forming the so-called "kettle-holes," by obstructed glacial drainage, or by the unequal deposition or settling of glacial debris. On the line between sections 21 and 22 the stream channel connecting these lakes has an elevation of about 838 feet A. T. In the less sharply morainic area southwest of Jones, Bear lake is without any outlet and is of morainic origin. The elevation is 883 feet A. T. Skyhawk lake on the road from Marcellus to Jones is on the northern edge of this moraine and drains into Rock creek. The elevation is 847 feet A. T. In the area west of Three Rivers in St. Joseph county there are numerous lakes imprisoned in the moraine area. Pleasant lake, in section 9, T. 6 S., R. 12 W., has an elevation of 58 feet above the Michigan Central depot at Three Rivers, the respective elevations being 795 and 853 A. T. The region is heavily covered with sand and gravel and may represent a cusp dumping ground.

Lake Michigan Glacier Lobe.

The eastern border of the Lake Michigan glacier lobe enters the lower peninsula a few miles east of the southwest corner of Cass county. From here there is a well defined morainal area leading to Cassopolis, varying in width from one to three miles. At Cassopolis the moraine is somewhat interrupted by glacial drainage from Stone lake which empties into Pokagon creek. Northeast from Cassopolis the east side of the moraine is west of and approximately parallel to the Grand Trunk R. R., leaving Cass county near the northeast corner of section 2, T. 5 S., R. 13 W. There is also a pronounced morainal ridge running northwest through section 3, T. 5 S., R. 15 W., north through section 22, T. 5 S., R. 15 W., and on up to Kalamazoo.

The elevation of this moraine is quite considerable. At the U. S. Lake Survey station in the southeast quarter of section 4, T. 8 S., R. 16 W., the altitude is 896 feet above sea level. On the road from Barron lake to Edwardsburg the moraine rises from an elevation of 774 to 859 feet A. T., on the west side, the greatest elevation being 894 A. T., in the east half of section 36. Going on towards Edwardsburg the drop is from 862 to 823 feet A. T. Just west of Cassopolis the greatest elevation is 931 above sea level. The west front of the moraine has an altitude of 889 feet on the same road. West from there the drop is quite rapid, the elevation of the old glacial channel on the north line of section 33 being 826 feet or

32 feet lower than the same drainage outlet between the east side of the moraine and the city of Cassopolis. On the road leading north from Penn the foot of the moraine has an elevation of 896 A. T., at the east quarter post of section 9, T. 6 S., R. 14 W. Just north the crest rises 48 feet. One mile north the elevation has increased to 968 A. T. at the east quarter post of section 4. The greatest elevation that I obtained within this tract is one-tenth of a mile west of the northeast corner of section 27, T. 5 S., R. 13 W., where the altitude is 982 feet A. T. On the western side of the moraine and east of Dowagiac, the west crest of the morainal accumulations are marked by a fine hill range well adapted for fruit culture. The elevation here is 943 feet A. T., and is four-tenths of a mile east of the northwest corner of section 3, T. 6 S., R. 15 W., the elevation of the corner being 840 A. T. The moraine falls off rapidly towards La Grange and is recessed by a creek valley, which heads in northeast of Volinia. On the quarter line road in section 22, T. 5 S., R. 15 W., the greatest elevation that I obtained was 895 A. T., which was one-tenth of a mile west of the east quarter post. Seven-tenths of a mile west the west front of the moraine is 891 feet above sea level. Mr. Leverett makes the elevation through here 930 feet A. T., and it is in deference to him that the 900 foot contour line is run. Very nearly one mile west the Michigan Central profile has an altitude of 842 feet A. T. To the west Dowagiac creek served as the cusp drainage for the west side of this lobe.

Lakes in Western Cass County.

Within this general area the elevations of several lakes were obtained. Barron lake, which serves as a water supply for Niles, is 754 A. T., or 75 feet above the Michigan Central depot there. Eagle lake, near Edwardsburg is 823 feet above sea level. Stone lake, which supplies Cassopolis with water, has an elevation of 857 feet A. T. The lake at La Grange, which is really a great mill pond, is 810 A. T.

Intermorainic Area.

In the area between the Michigan moraine and the interlobate area, the country is rolling, the present surface drainage being into the St. Joseph river. Christian creek is the largest stream in this territory. Most of the intermorainal area is contiguous to the Grand Trunk R. R., and that furnished data for the altitudes. At Edwardsburg, the elevation is 829 A. T., increasing to 891 feet A. T., at Cassopolis and 888 at Marcellus.

ELEVATION OF STREAMS.

During the course of this work considerable information was obtained relative to the elevation of streams. Given the amount of fall and the quantity of flow in the stream channel, we have two of the principal factors which determine its utility for water power. While the stream elevations here given are not always accurate, I believe that the amount of error is less than five feet. The gaging of streams does not fall within the province of this report. In Michigan, Mr. Robert E. Horton has had the establishment of water gage stations, over 60 stations being recently set. The results are published annually in the Water Supply and Irrigation Papers (49, 65, 75, 83), issued by the Division of Hydrography of

the U. S. Geological Survey. In this connection it should be mentioned that Mr. Horton has published some results of his work on water power in Water Supply paper No. 30, p. 22, et sequor, and in the Proceedings of the Michigan Engineering Society for 1901. In Water Supply and Irrigation paper No. 83, p. 265, the results of gage readings at Mendon are given.

In the report of the tenth census there is considerable information relative to dam locations in the southeastern part of the state.

Naming of Streams.

At the outset it was found that the nomenclature for streams is not very uniform or consistent. In the map of Branch county in Volume V of the Michigan Geological Survey report, Coldwater river is indicated as flowing into Hog creek, in the northern part of Branch county. Also in Rand-McNally's sectional map of Michigan there are two Bear creeks in St. Joseph county, while the Tiffin river in the western part of Lenawee county is formed by the union of another Bear creek and Hillsdale creek, the two streams uniting above Hudson. In the blue print maps which were used in the field, the St. Joseph river is called Nottawa creek, in its course in St. Joseph county above Three Rivers, being properly designated in its upper reaches in Branch and Hillsdale counties. In Rand-McNally's sectional map of Michigan Nottawa creek is represented as rising in the southern part of Kalamazoo county. From there the course is approximately parallel with the St. Joseph river, the outlet of the stream being three miles east of Mendon.

I believe that Mr. John F. Nellist's blue print maps which were used in field work are largely based on county atlases. In the same blue print maps Prairie river in the southern part of Branch county is indicated as emptying into another Hog creek, which otherwise is known as Spring creek, in its course through Centerville, and on to the St. Joseph river. The Pokagon creek on our blue print maps is called Putnam creek in the Rand-McNally map. I have used the former name as preferable. In Hillsdale county there are three St. Joseph rivers. One which has already been mentioned in the northwestern part of the county, passing through Jonesville and Litchfield. The other two are tributary to the drainage into Indiana, one flowing southeast through Camden. The third, which runs southwest in the same territory has a handle, being designated as St. Joseph of the Maumee, which is at least specific, if somewhat cumbersome.

I have not presumed to establish the nomenclature in all these cases. In the case of Nottawa creek the error is obvious and the name should be used as designated on Rand-McNally's map. The name Prairie river I have used instead of Spring creek, the duplicate name of Hog creek being only used for the stream in the northern part of Branch county. This is in accordance with common usage. The other streams are relatively unimportant. It is obvious, however, that there should be established some clear and consistent nomenclature.

Elevation of Streams and Dams.

In the list of improvements only the location of such dams and the elevation of stream courses are given as were obtained incidental to the main question of water supply. What I have endeavored to do is to determine wherever possible, and with as much accuracy as possible, the elevation of the different streams which will give some idea of their utility for water power when properly gaged, the elevation of the streams being obtained below the dams unless otherwise mentioned.

The River Raisin, according to Mr. Leverett, has an elevation of about 645 feet A. T. at Deerfield; of 664 feet above the dam at Blissfield; of 686 A. T. at Palmyra. Mr. Leverett makes the elevation at the R. R. crossing in section 21, Raisin township, 703; four-tenths of a mile east of Sutton of 715 A. T. At Tecumseh the altitude of the stream below the dam is 744 feet as determined by the U. S. Topographic Survey. The dam at this point is 18 feet high. The altitude below the dam at Clinton as determined by the Topographic Survey is 799 feet; at the Lenawee-Washtenaw county line of 808 feet A. T. Near Somerset Center the elevation is about 1026 feet A. T. Dams have been put in at Deerfield, Blissfield, Palmyra, Tecumseh, Clinton, River Raisin, and various other points as far up as Somerset Center. That at Palmyra is 5 feet high, but washed out this year, and at Somerset Center 11 feet. The mill at Somerset Center is situated not far from the head waters of the stream, which is fed by a large spring.

South Branch of Raisin River.

The south branch of the River Raisin is 731 feet above tide at Adrian and 831 feet high on the line between sections 2 and 3, T. 7 S., R. 2 E. Wolf creek is 935 A. T. high at Springville in T. 5 S., R. 2 E. and about 730 feet A. T. where it empties into the south branch of the River Raisin near Adrian.

Black Creek.

Black creek heads northeast of Hudson, emptying into the River Raisin about three miles west of Blissfield. On the section line 3 and 4, T. 8 S., R. 4 E. the elevation is 686 A. T.; ½ mile south of Jasper the height is 723 A. T.; near the northeast corner of section 15, T. 8 S., R. 2 E. the elevation is 783 A. T.; at the northeast corner of section 9, T. 8 S., R. 2 E. of 793 A. T.

Tiffin River.

Where the Tiffin river is crossed by the Lake Shore and Michigan Southern R. R. in section 24 of T. 8 S., R. 1 E. the elevation of the track as given by Mr. Leverett is 794 feet and of the stream about 775 feet A. T. One-tenth of a mile south of the northeast corner of section 36, T. 7 S., R. 1 W. the height is 869 feet A. T., the elevation increasing to 887 feet three-tenths of a mile south of the northeast corner of section 25 in the same township and range. At Hudson the stream is 898 feet above sea level. There are dams in the river in section 36 and at Tiffin.

In Cass county there are several small powers. Christian creek formerly had a dam at Vandalia. The elevation of the stream there is 861 A. T.

One-half mile south of the northeast corner of section 9, T. 7 S., R. 14 W. the elevation is approximately 847 feet A. T.

Pokagon creek is 730 feet high at Pokagon falling 55 feet where the stream crosses the road, six-tenths of a mile west of the northeast corner of section 31, T. 6 S., R. 15 W. This makes the fall very nearly 9 feet per mile. If the same rate is continued down stream to where the creek empties into Dowagiac creek, two miles west of Pokagon, the elevation would be approximately 712 A. T. for both streams. Mr. Leverett gives the elevation of Dowagiac creek on the north line of section 16, T. 6 S., R. 16 W. as 720 A. T. In the northeast quarter of section 27, T. 5 S., R. 16 W. the elevation of the north fork is about 723 A. T. increasing to 728 feet near the northeast corner of section 24, T. 5 S., R. 16 W. The south fork of this stream is 800 feet A. T. below the 10 foot dam at La Grange. The millpond here floods over several fractional sections of land. Near the corner of sections 1, 2, 11, and 12, T. 6 S., R. 15 W. there is another power utilized by a farmer for a feed mill. Between the two forks of Dowagiac creek is situated what is known as the Marguerite mill. This is on the quarter line of section 13, T. 5 S., R. 16 W. The creek there is tributary to the north fork of Dowagiac creek and is 738 feet A. T. The dam is 8 feet high. There are probably a number of small powers along Dowagiac creek and its tributaries which could be utilized for local milling purposes or village electric light plants.

St. Joseph River.

The St. Joseph river of lower Michigan and northern Indiana rises north of Hillsdale and empties into Lake Michigan at St. Joseph. In St. Joseph county at Constantine the stream has an elevation of 762 feet A. T. Mr. James E. Bunn, city clerk of Three Rivers informs me that "the water in the St. Joseph river below the dam at the St. Joseph cement bridge is 14.5 feet below the top of the rail of the Michigan Central R. R. track at their depot."

"The water in the race adjacent to the M. C. depot is 8 feet below the top of the rail at that point."

"The water in the St. Joseph river below the dam at the St. Joseph cement bridge is 11.2 feet below the top of the rail of the L. S. & M. S. R. R. tracks at their depot."

"These measurements were taken in August, 1902, when the water was at an ordinary stage—neither low nor high. At the present time (Nov. 10, 1903) there would be considerable difference, owing to the low stage of the water."

The elevation of the Michigan Central tracks at their depot is 795 feet A. T., which would make the elevation of the river 780 feet A. T.

In the east half of section 10, T. 6 S., R. 11 W. the river is approximately 795 feet A. T. under the bridge. One-tenth of a mile south of the east quarter post of section 27, T. 5 S., R. 10 W. in the village of Mendon, I made the elevation 826 feet A. T. There is a gage located here. Where the stream is crossed by a bridge in the northeast quarter of section 3, T. 6 S., R. 9 W. the altitude is approximately 835 feet A. T.

In Hillsdale county the river has an elevation of 991 A. T. at Litchfield, and of 1085 feet at Jonesville. There are dams at both places, the one at Jonesville being an overflow dam between 6 and 7 feet high.

Fawn River.

This empties into the St. Joseph river in Constantine, where as we have seen, the elevation of the main stream is 762 feet above tide. Where this tributary river is bridged in the northwest quarter of section 28, T. 7 S., R. 11 W. the height is 797 feet. At the intersection of the G. R. & I. R. R. one mile south of the Michigan state line the elevation has increased to 855 A. T. This stream drains the region south of the Sturgis moraine, and a small part of northern Indiana.

Prairie River.

This water course, which is otherwise known as Hog creek or Spring creek in its lower reaches, has two forks in the south central part of Branch county, one rising in Pleasant lake, the other in Cook lake. Westward the river passes near Burr Oak, through Centerville, emptying into the St. Joseph river not far south of Three Rivers. The following elevations were obtained: Just south of the Michigan Central R. R. at Centerville the height is 803 A. T. Where the stream is crossed by the G. R. & I. R. R. less than one-half mile east of Nottawa the elevation of the stream is 825 feet above sea level. Just north of the northeast corner of section 22, T. 7 S., R. 9 W. the altitude has increased to 859 feet A. T.

In Branch county one-tenth of a mile south of the northeast corner of section 26, T. 7 S., R. 8 W. the height is 911 A. T., increasing to 930 feet, two-tenths of a mile north of the southeast corner of section 32, T. 7 S., R. 7 W.

Portage River.

This stream unites with the St. Joseph river at Three Rivers, where as we have seen, the elevation is 780 feet A. T. Three-tenths of a mile south of the northeast corner of section 27, T. 5 S., R. 11 W. the height is about 820 A. T. Where the stream is crossed by the G. R. & I. R. R. in section 22, T. 5 S., R. 10 W. the elevation is 835 feet A. T. This stream rises in the eastern part of Kalamazoo county running southwest.

Bear Creek.

This water course runs across the southeastern part of Kalamazoo county, emptying into Nottawa creek west of Leonidas. Where the two streams unite two-tenths of a mile west of the east quarter post of section 20, T. 5 S., R. 9 W. the elevation 838 feet A. T.; dam 4 feet high.

Hog Creek.

This water course runs northwest from the west central part of Hillsdale county to its junction with the St. Joseph river at Union City in the northern part of Branch county. At the north quarter post of section 23, T. 5 S., R. 6 W. the elevation of the stream is 945 feet above sea level, increasing to 967 feet A. T. at the northeast corner of section 29, T. 5 S., R. 5 W.

The elevation of numerous small water courses were obtained, but it is believed that the elevation of all the streams that can have any economic development is given.

CHAPTER IV.

WATER SUPPLY OF LENAWEE, HILLSDALE, BRANCH, ST. JOSEPH, AND CASS COUNTIES.

LENAWEE COUNTY.

Flowing Wells.

Within the limits of this county there are two principal areas in the lower parts of which flows have been obtained. In the eastern part of the county there are several flowing wells east of the Belmore beach, which follows approximately the road running northeast and southwest through Ridgeway, and west of the line 700 feet A. T. This area leads northeast of Lenawee Junction. I have not obtained the records of any flowing wells west or south of the River Raisin.

Within this area beginning at the northeast flows have been obtained at Britton, southeast of Ridgeway, Holloway, at the northeast of Raisin Center, in the east half of section 32, T. 6 S., R. 4 E., and at Lenawee Junction. At Britton the depth of wells varies from 25 to 50 feet deep, the elevation being about 698 to 700 feet A. T. In the east half of section 32 the flow is found in gravel at a depth of 186 feet; surface elevation 725 A. T. At Lenawee Junction the water is also found in gravel in the drift at a depth of 135 feet, the elevation A. T. being 714 feet. Most of the flows through here are small. It is quite noticeable that the depth increases to the south, which will have to be taken into account in prospective drilling.

Tipton-Rollin Artesian Area.

Another belt trending southwest from Tipton is described by Mr. Wm. Beebe of that place as being from ½ to 2 miles wide and extending northeast and southwest of Tipton for a distance of over 40 miles, the wells varying from 12 to 150 feet in depth, but mostly from 50 to 70 feet in depth. At Tipton the head is 900 A. T., the wells being 25 to 75 feet deep. In the valley of Wolf creek artesian wells are found at the southeast corner of section 1, T. 6 S., R. 2 E., at a depth of 81 feet. One mile south two flows were found at a depth of 94 and 76 feet the greater flow coming from the more shallow well. In section 10, T. 6 S., R. 2. E., at an elevation of 966 feet A. T., a fairly strong flowing well throwing water 10 feet above the surface was obtained at a depth of 58 feet. The water is slightly chalybeate both here and at Tipton. South from Rome Center and three-tenths of a mile east of the northeast corner of section 28, T. 6 S., R. 2 E. there is a strong flowing well at an elevation of 900 feet A. T. This is in the basin of the south fork of the river Raisin. The most westerly flow that I obtained any information of in this area, is the southwest quarter of section 27, where a flowing well is found at an elevation of 982 feet A. T.

The flowing wells in this tract are all found in the area between the 900

and 1,000 foot A. T. contour lines. In the low areas the probabilities for obtaining flows are fair, especially east of the morainal tract running south from Stoddard.

Addison and Woodstock.

In the northwestern part of the county flows are occasionally found at Addison and Woodstock at a depth of 25 feet. This is west of the Huron-Erie moraine.

Ground Waters.

In reviewing the water supply data for the rest of this county I have begun at the southeastern part of the county and worked by townships north and west, after the manner of the original linear survey. The advantage of this plan, however, is that some approximation is made to the altitude of the land, the difference of elevation affecting to a greater or less extent the depth at which water can be obtained. But this is mostly within circumscribed areas where the elevation is abrupt.

In the territory between Sisson, Blissfield and Riga the land is a plain varying in elevation from 665 to 700 feet A. T. The depth of wells is from 82 to 95 feet, water generally being obtained in beds of gravel. In one well in section 5, T. 8 S., R. 5 E. the rock was struck at a depth of 602 A. T. or 88 feet below the surface and the water is soft. In two wells in section 16, T. 7 S., R. 5 E. salty water is found at a depth of 82 to 95 feet. Water in bed rock will probably be salt?

In T. 6 S., R. 5 E., which includes the civil townships of Ridgeway and part of Deerfield the topography is level through the central portion. The elevation increases from 675 feet A. T. in the southern portion to 740 A. T. at Ridgeway. The depth to water is variously stated as from 13 to 100 feet. Wells having a depth of 13 feet are doubtless surface waters. Not only are they liable to contamination but the supply is generally insufficient in summer. Such sources of water supply should be deepened. Water is found in the drift and is generally hard. In two of the wells having the greatest depth of 87 and 100 feet the water is brackish. In general it would seem that a fair supply of water could be obtained at a depth of less than 30 feet. In a well 200 feet in depth situated in section 33, T. 6 S., R. 5 E. no water was found.

Macon Township.

The township of Macon corresponds to the government township of T. 5 S., R. 5 E. The elevation increases over 100 feet from the eastern border of the county to the divide east of the Raisin river. A fair amount of water is obtained at a depth of 20 feet or less, the water being hard. One well situated in section 27 entered rock at a depth of 120 feet, or 622 feet A. T. Mr. Frank Leverett is engaged in the preparation of a report on this, and the adjoining township to the west, in connection with his work on the Ann Arbor Quadrangle. The results are to be published by the U. S. Geological Survey.

Ogden Township.

In Ogden township, T. 8 S., R. 4 E. the well records showed a depth of from 60 to 115 feet. The township is a plain going north and east from the center, the elevation within that area being from 709 to 714 feet A. T. outside of Black creek, which is about 15 feet below the level of the surface, in the north central part. The water is found in gravel beds in the drift. In three wells having a depth of from 80 to 115 feet the water is impregnated with salt and sulphur. Around Ogden Center the average depth of wells is 100 feet.

Palmyra and Raisin Townships.

These occupy townships 6 and 7 S., R. 4 E. In this area all the wells of which I obtained information are found in gravel beds in the Pleistocene. The wells vary in depth from 37 to 186 feet, the water being generally hard, except in the well 37 feet deep. There are no wells mentioned in which salt or sulphur occurs. It is in a portion of this area that flowing wells are found. As has been mentioned Mr. Leverett is reporting on Clinton township to the north.

Fairfield and Madison Townships.

These lay south and west of Adrian in R. 3 E. South of Adrian the country is hilly for three or four miles, being rolling south of Fairfield and west of Jasper. Most of the wells are shallow, water being obtained at a depth of from 14 to 47 feet, the elevation increasing somewhat to the north. Water is obtained in sand and gravel beds in the drift, being generally hard. The supply is abundant.

Adrian and Franklin Townships.

These are townships 5 and 6 S., R. 3 E. and contain the flowing wells found at Tipton, and southwest from there. Like the wells south from here the water is hard. In Adrian township water is generally found at a depth of less than 40 feet in the drift, increasing somewhat in depth northward. Two miles south of Tipton water is obtained at a depth of 62 feet, which is the average depth for wells at Tipton.

Seneca and Dover Townships.

These are the government townships of 7 and 8 S., R. 2 E. East and north of Seneca P. O., which has been renamed Ennis, the country is rolling. Water is obtained from the drift in wells varying in depth from 10 to 110 feet. The water is generally hard. In two wells having a depth of 42 and 65 feet, in the southern part of Dover township the water contains iron. In several of the wells having a depth of less than 40 feet the supply is limited or decreasing. In a well 110 feet deep the capacity is 50 barrels per day. It would probably be well to go to a depth of over 50 feet for water supply. Mr. Chas. Middleton, section 27, T. 7 S., R. 2 E., states that the first 20 feet was red clay, changing to blue, with occasional beds of gravel. Under that 48 feet of sand in which the water was obtained.

Rome and Cambridge Townships.

These are townships 5 and 6 S., R. 2 E. The Huron-Erie moraine runs along the western part of Rome township and east northeast through Springville in Cambridge township. Dr. E. J. Ross of Rome P. O. writes that the east half and the southwest quarter of Rome township is rolling being composed of a heavy clay. The northwest quarter is "hilly and sandy." On the road from Tipton to Cambridge and south of Cambridge to Onstead the country within the moraine is hilly, with overwash beds of sand and gravel.

The average depth for wells around Rome center is 75 feet, the depth varying from 45 to 145. In two wells dug there the depth is 85 and 91 feet. The water rises 75 feet. Water is obtained in the drift from beds of sand or gravel. It is either hard or contains iron. In Rome township the supply is abundant, and as we have seen, the water head frequently reaches the surface producing flowing wells. To the north in Cambridge township the depth of wells varies from 16 to 48 feet, water in some cases being obtained about on a level with adjacent lakes. Where the supply has lowered, the causes seem to be local. The remedy probably lies in either having the wells sandpumped or increasing the depth. Wells are found in the drift.

Medina, Hudson, Rollin and Woodstock.

In this tier of townships, forming the western part of Lenawee county, the water is generally found in the drift. In one well in section 21, T. 6 S., R. 1 E., having a depth of 265 feet, the well entered rock at about that depth. This is 806 A. T. At the Hudson water works the city is supplied with 8 wells 6 inches in diameter, which are capable of supplying 300,875 gallons per day. In general throughout this region the supply is abundant at depths varying from 25 to 100 feet. Mention has already been made of the artesian wells in the northwestern part of the county.

HILLSDALE COUNTY.

Wright and Pittsford Townships.

These townships are located in the southeastern part of Hillsdale county, constituting townships 7 and 8 S., R. 1 W. Water is found in gravel beds at a depth of from 10 to 245 feet as at Pittsford. The supply is ample. Water is generally hard except in a well 71 feet deep which is reported soft. The depth at which water is usually obtained is from 35 to 95 feet. In the deep well at Pittsford the supply was obtained from water bearing gravel at a depth of 245 feet, the water rising 145 feet. This is situated on a heavy morainal deposit.

Wheatland and Somerset Townships.

These are townships 5 and 6 S., R. 1 W. Mr. A. C. Lane has represented the greater portion of this area as underlaid by the Marshall sandstone. In Wheatland, T. 6 S., R. 1 W., I did not obtain the record of any wells into the rock. But they would probably yield water as the Marshall sand-

stone is a good source of supply. In Somerset township, section 8, rock was struck at an elevation of 1,163 feet A. T., dropping in section 23 to 1,037 A. T. A flowing well was obtained in section 1 of Wheatland, and near Somerset. There is also a very fine flowing well in section 16, T. 6 S., R. 1 W. This is found in a narrow valley and is isolated. The amount of flow is 23.37 gallons per minute. Flows are also obtained at Jerome at a depth of 30 feet. Throughout the central part of these townships there is an abundant supply of hard water. Springs are abundant near Jerome.

Ransom and Jefferson Townships.

In these civil divisions constituting townships 7 and 8 S., R. 2 W., the depth to water in Ransom township varies from 20 to 90 feet, throughout the central portion the average depth being 53 feet. The land is rolling. In Jefferson township to the north the depth varies from 14 to 79 feet, the average depth around Osseo being given as 50 feet. There are no flows throughout here that I obtained information of. The water is hard and occasionally contains iron. Water is from gravel beds in the drift. Osseo is near the edge of a moraine which follows approximately the course of the Marshall sandstone. The drift accumulation is probably considerable, but an abundant supply of water is obtainable if the supply from the drift should fail. In Jefferson township the depth to water varies as much as the surface.

Adams and Moscow Townships.

These are townships 5 and 6 S., R. 2 W. Almost the entire area is represented as underlain by the Marshall sandstone in Mr. Lane's most recent geological map of Michigan. The depth to water varies from 18 feet near Lake Adams, where the surface elevation of the well is 1,136 A. T., the water being found at 1,118 and the elevation of the lake is 1,117. North from here in section 21, T. 5 S., R. 2 W., water is found in the Marshall sandrock at a depth of 95 feet at an elevation of 1,164 A. T., rock found at 50 feet. In a well in section 3, T. 5 S., R. 2 W., sandrock is said to have been struck at a depth of 14 feet; surface elevation 1,104 A. T. A well in section 21, T. 6 S., R. 2 W., entered rock at 70 feet; the well top is 1,160 A. T. The elevation of the rock surface, therefore, is from 1,090 to 1,115 in the central portion of Adams and Moscow, the average amount of drift being 50 feet more or less. Throughout this area there is an abundant supply of hard water both in the sandrock and the drift.

Woodbridge and Cambria Townships.

These form townships 7 and 8 S., R. 3 W. of the linear survey. In this valley of a tributary to Cubb lake there are two flowing wells found in sections 22 and 26, T. 7 S., R. 3 W. The region is very hilly. Areas in which flows are likely to be obtained are constricted in area. The depth to water varies somewhat according to the elevation of the land. Thus we have a well 32 feet deep at a height of 1.048 A. T. in section 11, T. 8 S., R. 3 W., the greatest depth increasing to 96 feet at an elevation of 1,089 A. T. in section 34, T. 7 S., R. 3 W. Where relatively high elevations of

land cover a considerable area the catchment basin generally increases with the surface. The reverse is true where the elevation approaches a knob formation.

Fayette and Scipio Townships.

These are townships 5 and 6 S., R. 3 W. Around Jonesville the depth to water is from 20 to 100 feet, at Hillsdale 35 feet, and at Mosherville 24 feet. In all three places an ample supply of hard water is obtained. The greater part of this area is underlain by the Marshall sandrock, forming a continuation of the region to the east. The greater part of the water supply comes from the bed rock. A spring on the farm of Arthur Merchant, in section 29, T. 5 S., R. 3 W. is said to flow from this sandrock. This is in the valley of the St. Joseph river.

Camden and Reading Townships.

Artesian wells have been obtained at Reading and in sections 18 and 19, T. 7 S., R. 4 W., the depth to water varying from 70 to 90 feet. This depressed area runs north and south, west of the elevation around Reading, and may furnish flowing wells at other localities. At Reading the Coldwater shale was struck at about 55 feet. In section 2, T. 7 S., R. 4 W. the Marshall ? sandstone was found under 22 feet of drift at 1,115 A. T. Again in section 22 of Reading township rock (Marshall?) was struck at 1,117 A. T. with an abundant supply of water. All the northeastern part of this township is probably underlain by the Marshall, which is a good bearer of water. The rest of this area is underlain by the blue Coldwater shales, with occasional thin beds of limestone. This is a poor water carrier, and wells will be sunk to best advantage in the overlying drift or soil formation. In Camden, T. 8 S., R. 4 W. the drift is 112 feet thick in section 15 and furnishes a steady supply of hard water.

Allen and Litchfield Townships.

These are townships 5 and 6 S., R. 4 W. Water is hard but there is an abundance of supply at depths variously ranging from 25 to 60 feet. The elevation of wells varies from 1,011 to 1,113 A. T. in the central portion of this area while the level reached by wells is from 997 to 1,098 A. T. This makes the extremes of the surface and water elevation very nearly the same. Marshall sandrock was struck at a depth of 15 feet in section 34, T. 6 S., R. 4 W., elevation 1,098 A. T.; in section 28, T. 5 S., R. 4 W., at about 28 feet or 997 A. T.; in section 13, T. 5 S., R. 4 W. at 40 feet or 1,027 A. T. The probabilities are that the eastern half of both of these townships are underlain by this water bearing sandstone, as well as the north and east half of Litchfield township.

BRANCH COUNTY.

This county is underlain almost entirely by the Coldwater shale, which as we have seen, is a poor water producer. Therefore throughout the county water is found in the drift formation at a depth of less than 100 feet. The water is almost uniformly hard, and occasionally contains iron. In lake regions wells are generally shallow, the depth to water being the same as the elevation of the lake surface.

Algansee and Quincy Townships.

In the central portion of these townships the depth to water is from 15 to 38 feet, the elevation of the water horizon rising and falling with the elevation of the surface. The supply is abundant, the wells at the Quincy water works having a capacity of 20,000 gallons per hour. The supply is generally sufficient for all needs.

Kinderhook and Ovid Townships.

These are townships 8 and 7 S., R. 6 W. In the former township the average depth is from 18 to 40 feet, the average depth around Kinderhook being 25 feet. In the township north, the depth varies somewhat in the hilly region. Thus in a well in section 21, the depth to water is 12 feet, the well being 856 A. T. North in section 16 the depth has increased to 90 feet, the surface elevation increasing 106 feet and the water horizon 28 feet. These elevations are more or less local. In section 18, T. 7 S., R. 6 W. the depth to water is 65 feet.

Coldwater and Girard Townships.

These are the government townships of 6 and 5 S., R. 6 W. In these two civil divisions the average depth to water is approximately 30 feet. The supply is abundant. In section 33, T. 6 S., R. 6 W. rock was struck at a depth of 36 feet elevation A. T. 960 feet. The water horizon varies from 900 to 1,000 feet A. T., oscillating more or less with the elevation of the surface.

Gilead and Bethel Townships.

These are respectively townships 8 and 7 S., R. 7 W. Around Gilead depth to water varies from 30 to 90 feet, the average depth being given as 30 feet. The supply is ample. The water horizon varies with the inequalities of the surface, maintaining throughout this area an average depth of approximately 25 feet in the central portion north and south. The supply comes from sand and gravel, and is abundant.

Batavia and Union Townships.

These constitute townships 6 and 5 S., R. 7 W. The average depth to water is very nearly the same as south of here or from 30 to 40 feet. Around Batavia the depth varies from 15 to 30 feet, increasing northward to 40 feet around Union City. The supply is ample except in the elevated morainal region north of Ensleys lake, where wells have been sunk to a depth of 50 feet, only obtaining a limited supply. I believe that a sufficient supply could be obtained within that area which is embraced approximately by the 950 foot contour line, by increasing the depth to 75 feet. The highest elevation that I determined within that tract is near the east quarter post of section 4, T. 6 S., R. 7 W. This is 990 A. T. At Union City a dry well 250 feet deep was sunk.

Bronson, Mattison and Sherwood Townships.

These townships are in the western part of the county and form townships 7, 6 and 5 S., R. 8 W. At Sherwood drilled wells are from 75 to 110 feet deep. On the moraine southeast of there the elevation increases 80 feet on the side of Mattison lake. In that neighborhood, however, wells sometimes strike water at an elevation of the lake surface, which is approximately 889 feet A. T. Through Mattison township the depth to water averages 45 feet, the elevation of the water horizon being 20 feet above the wells at Sherwood.

ST. JOSEPH COUNTY.

This county is also underlain by the Coldwater shale formation. Throughout the county water is generally found in sand and gravel beds in the drift or soil formation, properly known as the Pleistocene. I have not obtained any information relative to flowing wells in this territory, though there are numerous flowing wells at Klingers Lake and a few elsewhere in the county. The supply is generally ample. Like most of the wells from the drift the water is generally hard, and sometimes impregnated with iron.

Fawn River and Burr Oak Townships.

These form townships 8 and 7 S., R. 9 W. A fair average for wells in this locality would be 45 feet. On the south side of the Sturgis moraine, however, in section 5, T. 8 S., R. 9 W. the water horizon is at the same elevation as in Burr Oak township, the elevation increasing so that the distance to water, on an average, is 100 feet.

Colon and Leonidas Townships.

These are townships 6 and 5 S., R. 9 W. In this area the elevation of Sturgis lake is 835 feet A. T.; of Palmer lake 840 A. T. In the records of all the wells that I obtained between Leonidas, Colon, and thence on the road to Burr Oak, the elevation of the water horizon is within the elevation of these lakes. The maximum elevation obtained in this district is on the line of sections 2 and 3, T. 7 S., R. 9 W.; 909 A. T. The depth there to water would be about 69 feet, decreasing to 40 feet at Leonidas, where the elevation is 860 A. T., and to 25 feet in section 15, T. 6 S., R. 9 W., which is 866 A. T.

Sturgis and Sherman Townships.

In the Linear Survey these are townships 8 and 7 S., R. 10 W. Sturgis township lies south of the Sturgis moraine, or at least in its most pronounced development. On the road from Sturgis to White Pigeon the land is rolling for the most part, the fall amounting to 50 and 60 feet. The average depth to water in Sturgis township is the same as around Leonidas, amounting to 40 feet. The supply of water is abundant. At the Sturgis water works the capacity of the wells is 125,000 gallons per day. Mr. E. B. Gray, Supt. of the Sturgis water works, has very obligingly given an analysis of the water from the two wells there.

Sturgis Water Works.	Grains per U. S. gallon. Open well.	Driven well.
Sodium carbonate	none	none
Lime carbonate	15.42	16.5
Magnesia carbonate	5.52	6.10
Lime sulphate	2.66	2.63
Magnesia sulphate	none	none
Sodium chloride	2.63	2.63
Free acid	none	none
Iron oxide and silica	0.20	0.23
Volatile organic matter	4.07	6.16
Total solids	30.50	33.80

It will be observed that the Sturgis moraine occupies the greater part of Sherman township to the north, the contour lines showing an elevation of 1,000 feet. Within this tract water in sufficient quantities is generally difficult to obtain, at depths of less than 100 feet.

Nottawa and Mendon Townships.

Going north these constitute townships 6 and 5 S., R. 10 W. Throughout this area the depth to water varies from 18 to 70 feet, the average around Mendon being variously given as from 20 to 70 feet in depth. The supply of water is generally ample.

Florence, Lockport and Park Townships.

These are townships 7, 6 and 5 S., R. 11 W. In these townships the water-bearing conditions seem quite fairly identical where I obtained records between Moorepark, Parkville, Centerville and thence southwest and west to White Pigeon. The average depth to water is 25 feet, wells varying in depth from 16 feet as in Sec. 3, T. 7 S., R. 11 W., to 40 feet in section 26, T. 5 S., R. 11 W. At Parkville the average depth is given as 14 feet the depth increasing to 27 feet at Flowerfield in the northwest portion of Park township. At the Three Rivers waterworks, and section 14 of the same township, flowing wells have been obtained in the valley of the St. Joseph river. The supply is ample.

Mottville, Constantine, Fabius and Flowerfield Townships.

In the Government Linear Survey these are respectively townships 8, 7, 6, and 5 S., R. 12 W. In Mottville township the average depth to water is very nearly the same as in the area last discussed. At White Pigeon the average depth is from 26 to 28 feet, decreasing to 20 feet at Mottville, which is in the valley of the St. Joseph river. At Constantine the topography is quite irregular as will be seen by referring to the contour map. Water is obtained there at depths variously ranging from 15 to 60 feet. Going north on the interlobate moraine a well in section 10, T. 7 S., R. 12 W. obtained an ample supply of water at a depth of 50 feet. The elevation of the well is 63 feet above the depot at Constantine. On the same moraine in the lower part of Fabius township water is generally found at a depth of 90 feet, increasing in depth northward, until in sec-

tion 28, T. 5 S., R. 12 W., it is over 100 feet to water, which is found in the drift. In the valley of Rock creek, at a much lower elevation, there are springs at Howardsville.

CASS COUNTY.

Throughout this county the water supply is either obtained from the drift or from lakes or running streams. The county is underlain by shale rock, which is almost invariably a poor water producer. Flowing wells have been found in several localities, but apparently on low ground, with restricted areas. Most of the artesian wells are in the northern tier of townships. Northwest of Marcellus, at Fish lake, there is such a well 90 feet deep belonging to Dr. Davis. Two miles east of Wakelee there is another flow north of the interlobate moraine. Thence west in the township of Wayne, T. 5 S., R. 15 W., there are flowing wells at Glenwood, and at Dowagiac flows are obtained at 100 feet, which are utilized in the city water supply. West of Glenwood at Long lake there is another artesian well. In section 35, T. 5 S., R. 16 W., a flowing well 152 feet deep in the drift flows 1 barrel a minute. South of these localities a flowing well was obtained at a depth of 33 feet in section 19, T. 6 S., R. 14 W. There are also a few flows at Summerville in the valley of Dowagiac creek, the water being obtained from 30 to 100 feet.

Porter Township.

This civil division includes the government townships of 8 and 7 S., R. 13 W. Within this area there are generally 2 or 3 water horizons. In T. 8 S., R. 13 W., water is obtained at depths varying from 20 to 100 feet, but the elevation at which the water is found apparently varies more than the surface. In this area fine springs are sometimes found at the foot of the moraine. Going north the elevation increases after the crest of the moraine on the south side has been reached. Water through here is obtained at depths varying from 55 to 160 feet, the records showing that water was found at from 55 to 60 feet deep; at 120 to 125 feet; and from 160 to 165 feet in depth, the elevations of the water horizons A. T. respectively on an average of 835, 766, and 735 feet. The water is hard and is from beds of sand or gravel. In section 27, T. 7 S., R. 13 W., the following section was obtained:—

	Feet.
Surface soil and clay	3
Sand	53
Blue clay	2.5
Water bearing sand	23
Total	81.5

Newberg and Marcellus Townships.

These occupy townships 6 and 5 S., R. 13 W. In section 10, T. 6 S., R. 13 W., springs are found in great abundance. On the interlobate moraine in sections 9 and 16, T. 6 S., R. 13 W., the depth of water is from 100 to 130 feet, decreasing to 25 feet north towards Marcellus. In section 21 a

well was sunk 199 feet without getting through the drift. The average depth to wells in Newberg township is 97 feet. At Marcellus the drift is over 208 feet thick. Drove wells there are from 12 to 25 feet deep, tubular from 60 to 100 feet. The average depth for wells in Marcellus township is about 45 feet.

Calvin, Penn and Volinia Townships.

These are townships 7, 6 and 5 S., R. 14 W. In the heavy morainic region in Calvin township, and adjacent thereto the depth to water varies from 50 to 90 feet, the average depth being about 65 feet. Northward in Penn, T. 6 S., R. 14 W., the average elevation is approximately the same, going north and south through the township. The water horizon, however, rises over 30 feet, making the depth to water 20 to 40 feet. At Penn wells are from 20 to 70 feet in depth; at Wakelee in the neighborhood of 50 feet, but occasionally 200 feet in depth. Around Vandalia the depth varies from 10 to 120 feet, those at 10 feet being surface water. Going north into Volinia the depth increases somewhat with the elevation, water being obtained from 60 to 115 feet, or on an average of 83 feet, more or less. Throughout these three townships there is generally an abundant supply of hard water.

Ontwa and Jefferson Townships.

These constitute townships 8 and 7 S., R. 15 W. Around Edwardsburg the depth to water is about 26 feet. The water is said to rise and fall in the wells, according to similar variations in the lake near Edwardsburg, but I am unable to find any very close agreement in the elevation of the water horizon and that of the lake surface which is over 10 feet higher.

In section 14 of Jefferson there are a number of springs. Going through this township on the road from Edwardsburg to Milton, the depth to water varies from 35 to 50 feet, the average of several wells giving 40 feet. In the hilly morainic region in the western part of this township the depth quite probably increases to 80 feet in places. At least this is true of the extension of this same hill region between Edwardsburg and Barron lake in Howard township.

La Grange and Wayne Townships.

In the Linear Survey these are townships 6 and 5 S., R. 15 W. The city of Cassopolis obtains a supply of soft water from Stone lake, which is supplemented by water from wells. Between Cassopolis and La Grange the depth to water varies with the surface, the water horizons in sections 22 and 26 being 35 feet below Stone lake. An abundant supply is obtained at a depth of 70 feet north of Cassopolis becoming less towards La Grange.

On top of the moraine which crosses the town line in section 4, T. 6 S., R. 15 W., the depth to water is 140 feet, as at Mr. Henry Springsteens. From here the elevation decreases to 30 feet in section 10, T. 5 S., R. 15 W. There are at least two water-bearing gravel beds in Wayne township, the lower water horizon in the morainal region probably outcropping in the springs at Glenwood, which are at very nearly the same elevation above tide.

Howard, Pokagon and Silver Creek Townships.

These are townships 7, 6 and 5 S., R. 16 W. Around Barron lake the depth to water is 20 feet increasing to 40 feet or over in section 4, T. 7 S., R. 16 W. On the road from Barron lake station to Edwardsburg, water is obtained on the moraine at 80 feet, at very nearly the top of the moraine or hill range. Between Pokagon and Dowagiac the land is rolling somewhat, the extremes of elevation being very nearly 50 feet. In this region water can be obtained at from 15 to 35 feet in depth. Around Pokagon the average is given as 25 feet with an ample supply of water. At Summerville there are a great many springs in the valley of the Dowagiac creek. The 11 flowing wells at Dowagiac which furnish part of the city water supply are 100 feet deep and have a capacity of 600 gallons per minute. The two dug wells 47 feet in depth, which are part of the same plant have a capacity of 400 gallons during the same time. The water is hard and contains iron. I am indebted to Mr. Mann for a record there.

Dowagiac City Well.	Feet.
Black muck and fine sand	2
Sand and small stones	3
Fine sand	2
Stones and gravel	15
Sand and gravel	10
Water-bearing gravel	15
Total	47

ACKNOWLEDGMENTS.

General acknowledgment is due to a large number of persons who have rendered assistance, mainly by replies to schedules. I am particularly indebted to Alfred C. Lane for the free use of data accumulated in the office both before and since the publication of his water supply papers in 1899, and for criticisms and suggestions in this article. Mr. Frank Leverett has also greatly added to the completeness of this report. Thanks are due to him for the history of the glacial retreat as given in Chapter III and for several locations and names of the several moraines. Also for information and criticism relative to artesian wells, and the elevation of the River Raisin. For the altitudes in this report, however, I am almost entirely responsible. In obtaining these data, each line of aneroid elevations began and ended at the railroad station for nearly every day's work, and generally I was able to make a railroad depot at noon time, obtaining a check above tide on the barometer before and after dinner. In addition to this a self recording barometer was left at a railroad base, which gave the variation in feet per hour. Several railroad profiles have been obtained by Mr. Lane, and these were used to obtain independent elevations above sea level.

Finally, I wish to express my indebtedness to Prof. C. A. Davis of the University of Michigan for his notes on the water supply of Tuscola county. Prof. W. H. Sherzer who is engaged in the preparation of a report on the geology of Wayne county has also materially added to the completeness of this paper by his information on artesian wells there.

Lansing, Michigan, November 24, 1903.

ANALYSES OF LOWER PENINSULA WATERS.

In connection with Mr. Cooper's paper it seems well to give a number of analyses of waters that have been collected since the issue of Water Supply Paper No. 31, as such analyses are of interest to manufacturers and makers of boiler compounds, when the waters are liable to be used in boilers, and are also of interest medically and to cities. We divide them into three classes. (1) Surface waters; (2) shallow wells; (3) deep wells.

1. Surface waters.

Detroit river waters are illustrated by the following analyses for the Water Works Commissioners, all in grams per metric ton (parts per million).

DETROIT RIVER ANALYSES.

	1.	2.	3.	4.	5.
Calcium carbonate	33.00	5.10	57.49	28.2	70.2
Magnesium carbonate	.....	.73	20.73	$\left\{\begin{matrix}Mg\ Cl_2 \\ 3.50\end{matrix}\right.$	1.53 1.14
Ferrous carbonate	8.14	21.60	trace.	8.9	.67
Sulphate of lime	.....	2.54	17.89	43.3	1.20
Sulphate of soda	7.50	7.50	$\left\{\begin{matrix}Na_2\ CO_3 \\ 5.75\end{matrix}\right.$	.....	$Na_2\ CO_3$ 5.5
Sulphate of potash	2.83	2.83	trace.	$\left\{\begin{matrix}K\ Cl \\ 2.47\end{matrix}\right.$	.....
Phosphate of lime	31.10	51.92	.....	$\left\{\begin{matrix}(of\ Al) \\ 0.58\end{matrix}\right.$	.....
Alumina	10.50	10.50	4.13	10.18	.....
Silica	5.00	5.83	5.24	4.5	4.8
Chloride of sodium	trace.	trace.	3.93	.61	4.13
H_2S	.....	trace.	.....	.....	.....
Oxygen with permanganate	1.11	1.42	.....	.....	.....
Total	98.07	108.39	115.16	103.7	108.0

1. S. H. Douglass, Feb. 11, 1854. Iron pipes, evidently imperfect. Note date.
2. S. H. Douglass, Feb. 11, 1854. Log pipes, evidently imperfect.
3. Frederick Stearns, (A. B. Lyons), inorganic constituents, Sept. 10, 1879, hydrant, quite unlikely to be so much sodium carbonate, better sulphate.
4. S. P. Duffield, 1861.
5. M. C. Fluke, 1877.

These analyses should be compared with analyses 4 to 8 and 5a, 6a and 7a of Water Supply Paper No. 31. The variation is more one of analytical combination and error, than in the quality of the water probably. No. 1 here is the same as No. 5 there, but is repeated for the sake of its companion No. 2. The total solids are 100—115 parts per million, and of these about 75 parts are calcium magnesium carbonates, more or less replaced by sulphates, of which there may be about 10 parts additional. There are about 5 parts silicia, 10 parts alumina, chlorine varies according to the purity of the water probably, but there is not less than 4 parts

of chlorides, about half of which may be combined with potash. The hardness is accordingly about 5°. The presence of carbonate or sulphates of soda may account for the water being less hard than say Lake Michigan or Detroit river or most of the Michigan rivers. Probably the waters from Georgian Bay also are less hard.

The analyses below show the water of Pine river at Alma.

PINE RIVER.

A. N. Clark, Analyst.

	Parts per thousand.	Parts per thousand.
Total solids	.26940[1]	.34148[2]
Inorganic matter	.22188	.26444
Organic matter	.04752	.09504
	.53880	.70096
Free ammonia	.00020	.00060
Insoluble in HCl	.01050	.01200
$(Al_2\ Fe_2)\ O_3$	.00300	.00730
Ca O	.07249	.07562
Mg O	.03098	.03084
$S\ O_3$	.02229	.03018
Cl	.00300	.00500
	.14246	.16154

To Mr. W. M. Courtis we owe a number of water tests, which though incomplete are of interest. They were mainly made for a special purpose,—to test the water for beet sugar or boiler purposes. The following two are of (1) Clinton lake and (2) Clinton river:—

[1] Above dam-7:10 A. M., September 16, 1902.
[2] 465-ft. below mouth of factory sewer-8:30 A. M., September 16, 1902.

CLINTON RIVER.

Character.	Both neutral carbonates.	
	1.	2.
Temporary hardness in parts per 1,000,000	105.3	.....
Permanent hardness in parts per 1,000,000	34.0	.....
Total	139.31	116.
Compared with Detroit river	2.7	2.2
Suspended matter	3.71	.....
Solid salts	280.	.....
Lime as carbonate	119.40	114.84
Magnesia carbonate	55.82	50.43
Soda and potash	1.65	.....
Silica	2.24	288.
Alumina (with ferric oxide)	.29	14.73
Organic matter with crystallization water	100.60	108.
CO_2	present	in both.
Cl	traces	in both.
Phosphoric acid	.....	trace.
Molassegenic salts (harmful in making sugar) very small	.....	.....

The following tests are of Calumet river, which is a neutral carbonated water, a good deal like Clinton river, with the salts mainly carbonate of lime and magnesia, with traces of sulphuric acid and chlorine. For boiler water there should be 76% allowance.

CALUMET RIVER.

	Parts per million $Ca\,CO_3$
Temporary hardness equal to	134
Permanent hardness equal to	191
Total (19° or)	325
Solid salts	460

Compared with Detroit river, 4½ times harder.

The character of the following Oxford water is unknown,—it may be a shallow well, but I think probably not. It is also a neutral carbonated water. I have made some emendations.

OXFORD.

	Parts per million gals. Ca CO_3.
Temporary hardness equal to	140.6
Permanent hardness equal to	55.4
Total (11.4 or)	196.0
(Clarke's scale, Courtis 6.2.)	
Solid salts	233.38
Organic matter	58.8
Sulphuric acid	0.26
(For boiler water 9.81.)	

It is probably an ordinary hard (calcium carbonate) water. The following tests of a water from Pinconning were to test its fitness as a boiler water. It compares most closely with Owen's test of a surface water at Kawkawlin river, among his Bay county analyses (Annual Report for 1902). It is also neutral carbonated. The hardness is equal to 236 parts (per million Ca CO_3).

PINCONNING.

Clarke's scale 3 to 4.	
Compared with Detroit river it is 2.14 times as hard.	
Suspended matter	350.
Solid salts	600.

(It must undoubtedly be salty as so many of the Bay county waters are.)

Lime, magnesia, ferric oxide, organic matter, carbonic and sulphuric acids, and chlorine present.

2. Shallow wells and springs.

The following is an analysis of the Owosso mineral water, which comes out of the side of a moraine just north of town, flow—11 barrels per minute with a temperature of 50° F. This is practically the same as No. 227 of the Water Supply Paper No. 31. The analysis is by Prof. S. P. Duffield and reduced from grains per imperial gallon by dividing by 70 while the analysis there is the same but the gallon was assumed to be the U. S. gallon, which it proves not to be.

OWOSSO.

		Carbonate.
Calcium bi-carbonate	366.7	227
Magnesia bi-carbonate	272.8	157
Iron bi-carbonate	227.4	148
Sodium (and potassium) chloride	30.0	30
Silica and alumina	8.8	9
Total	905.7 904.9	571

The water is rather unusually strong in carbonates, and the salts must (see page 212 of part 3, of Vol. VIII) be in the form of bi-carbonates.

But of course on evaporation this would be lost and the total solids left would approach the second set of figures.

On page 60 is given a partial test of the water of the Sanitas Spring, Topinabee, by Prof. J. V. Stanislaus. The water is from a well driven or drilled 130 feet through drift. The spring itself on August 17, was so piped that the temperature did not fall below 50°. It was a hot day. But near by a similar well at the railroad station had a temperature of only 48.8°, while near by at Indian River flowing wells ranging from 90 feet to 189 feet deep through 40 to 60 feet of sand and 20 feet of smooth clay had temperatures ranging from 47.6° up to 53° according to the amount of pipe and strength of flow.

These two are almost[1] at the extremes as regards hardness. I imagine the cause of this difference may lie in the fact that the Owosso spring draws from a comparatively narrow vein through the till, extracting all the lime it can from the highly calcareous till, while the Topinabee well taps a sand or gravel bed laid down in and full of water of an old glacial lake, which was relatively soft as melting ice generally is.

We have an interesting series of analyses near Durand. According to W. J. Richards, bed rock does not occur there until 180 to 210 feet down, so that the well record in Volume VIII, part 2, p. 199 must be corrected accordingly. The brown shale is then probably merely a pink or brown stratified clay. He says the springs south of town, analysis (4), are in lime beds. In putting down a well by the railroad he used water from the ditch but it was too salt. There is he says, 24 grains to the gallon, analysis (4), in a 200 foot well in the gravel. He has recently put down a well only 60 feet from the former Durand well 206 feet deep, with 51 feet of gravel. He thinks it would have been 210 feet to bed rock. Half way up West Main street there is a trough where the water has 6 feet head.

DURAND.

	4.	1.	3.	2.	5.
Depth	178 ft.	178 ft.	Spring.	91 ft.	Spring.
Calcium carbonate	87.1	46.0	205.	68.5	121.6
Magnesium carbonate	66.5	42.0	92.1	54.7	101.6
Sodium potassium sulphate	44.6	35.6	16.	14.8	8.9
Sodium potassium chloride	414.0	253.	17.2	57.3	28.6
Sodium potassium carbonate	34.3	158.2	36.0	93.0	23.0
Silica	16.3	4.0	2.2	8.2	4.5
Iron and Alumina	trace.	1.3	2.0	3.7	2.5
Total	661.5	540.1	375.5	300.2	290.7

We have arranged these analyses in order of decreasing amount of salts. Analysis (6) by Prof. Kedzie is stated in a slightly different form, but is not essentially different from 5 though only 50 feet deep. Nos. 5 and 6 represent the second water there and 4 and 1 the third, which is quite brackish. No. 6, the city water well, is about 6 to 10 rods from the

[1]Mrs. W. Peterson, West Olive, according to the U. S. experiment station at the Michigan Agricultural College has still softer water.

plant, and goes through 10—18 feet of blue clay, then sand and a little gravel and hardpan, striking the water-bearing gravel from 50 to 55 feet down, i. e., the second water.

No. 6. Depth 50 to 58 feet.	Parts per million.
Calcium carbonate	66
Magnesium carbonate	73
Calcium sulphate	23
Sodium chloride	46
Silica	10
Alumina and iron	13
Organic (volatile at red heat)	66
Total	297
Temporary hardness (removed by boiling)	6
Permanent hardness	8
Total	14

In total solids this closely resembles Nos. 2 and 5.
As to boiler use:

1. Gives little scale, will give corrosion, pitting, perhaps foaming.
2. Gives some scale, medium hard, slight foaming.
3. Fair water, twice as hard as No. 2, but not as hard as usual, considering total solids.
4. Gives some scale but more corrosion.
5. Average feed water, with considerable scale of medium hardness but not corrosive.

The deepest well is about three feet above the crossing. Rigg's and Sherman's map varies from 80 at the north to 103 feet above their datum, the crossing being 93. The deepest well was put down by J. Coryell.

Other wells around here at Byron, etc., are salty, and we must imagine that the Durand wells barely escape striking the Michigan series and do get some of the salty waters thereof. In fact if it is really as deep to bed rock there must be a valley in the rock surface here into which these brackish waters might easily collect.

In Volume VIII, part 2, is also found an analysis of Goose lake near Cement City, showing the character of the water in one of the marl lakes, the main constituent out of 282 parts per million solids is 262 parts per million calcium magnesium carbonate.

The following analysis by W. M. Courtis labelled Detroit Water, is certainly not a surface water, but probably of a shallow well:

Character	salt
Suspended matter	18.94 per gal
Solid salts	235.667
Lime as carbonate	22.649
Magnesia	with the lime
Soda and potassa, as chlorides	213.018
Silica and ferric oxide	with lime
Carb. acid	present
Sulphuric acid	present
Chlorine	present

EATON RAPIDS.

Analysis of Eaton Rapids water made by F. W. Robinson for Prof. W. C. Eslow.

Total solids	1.550000
Loss on ignition	.270000
Free ammonia	.000360
Albumenoid ammonia	.000100
N_2O_3 Nitrates and nitrites	absent
Cl	trace
SO_3	.0683800
SiO_2	.0019000
Fe_2O_3 (etc.)	.00054
CaO	.0638000
MgO	trace only
CO_2	considerable—not estimated

Quantities are in parts per thousand. Well cased 35 feet only; 185 feet deep.

Passing now to the wells into bed rock, but not very deep and with so little mineral matter as to be palatable drinking waters, we have to compare with Nos. 243 to 247 from Eaton Rapids the following, which is like the other wells in this group, high in sulphates and iron, low in chlorides, a typical coal series water.

Ashley, Chesaning, and Maple Rapids have waters unusually strong in sulphates relative to chlorides. The analysis at Ashley is as follows:—

ASHLEY.

	Per million.
Calcium carbonate	40
Calcium sulphate	693
Magnesium carbonate	146
Sodium chloride	666.8
Silica	8.8
	1554.6

Albion is another place where the various wells have been carefully studied, where also there are flowing wells. In the set of 13 analyses by Prof. Fall given below, we note that Nos. 1, 2, 3, and 4 penetrate into bed rock, entering the Marshall sandstone. The depth of the other wells is not known but they are not deep. No. 1, artesian flowing, possibly the National Bank well, which is now descended to by steps from the sidewalk. It used to flow above the street level and with force enough to

ANALYSES OF ALBION WATER.

BY DELOS FALL.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
Total solids	386.	309.	305.	232.	580.	600.	.....	500.	228.	614.	.....	428.5	571.
Chlorine	36.86	4.5	4.5	5.6	37.89	28.6	40.	74.3	7.14	32.8	32.8	51.4	42.8
Free ammonia	.228	.114	.062	.068	.096	.022	.08	.12	.046	.08	.07	.08	.006
Albumenoid ammonia	.048	.042	.062	.054	.068	.12	.26	.42	.024	.32	.14	.25	.40
Temporary hardness	.....	.....	.....	.....	.....	.....	100.	.....	93.5	14.3	.....	5	107
Permanent hardness	.....	.....	.....	.....	.....	.....	100.	.....	114.3	71.4	.....	80.7	93
Total hardness	307.	293.	293.	243.	279.	164.3	200.	.....	142.8	85.7	157.1	85.7	200.
Nitrates	0.	.3	0.	.75	.15	.....	.....	.....	.....	.....	.....	.....	.....
Nitrites	Minute trace.	0.	0.	0.	0.	.....	.....	.....	.....	.....	.....	.....	.....

spatter out of the cup, but now has lowered until there is not much head and it stops in dry weather. It is 200 feet deep, but the water is mainly at 100 feet, and yet the extra amount of chloride over 2 and 3 is doubtless from the greater depth.

No. 2. The Warner Spring, flowing, the city water is the same as this and the following practically. The city supply comes from 4 6-inch wells and 4 8-inch wells from 110 to 114 feet deep, which used to flow with 8 to 10 feet head. They are close to the river bank. In July they are rather short of water. A partial analysis of this is given in Water Supply Paper No. 31, analysis No. 69.

No. 3. Parmenter well, 100 feet deep, similar to No. 2. These three first wells agree very closely, and the amount of ammonia and chlorine found are no sign of contamination. The hardness is considerably greater than in the 30-foot shallow well No. 9, and may point to nearly complete saturation with bi-carbonate in the absence of free CO_2.

No. 4 is from the Albion Manufacturing Co.

No. 7 was slightly turbid, yellowish, and had bad odor on standing.

No. 8 was considerably turbid, slightly green, and had hardly any odor on standing.

No. 9 was from a well 30 feet in the rock, clear, colorless, and odorless.

No. 10. Slightly turbid, colorless, odorless.

No. 11. Clear, bluish, odorless.

No. 12. Clear, slightly yellow, odorless.

No. 13. Clear, colorless, odorless.

In Lansing we have an analysis of the well of the Piatt Bros. which is a more or less mixed water. The analysis made at the M. A. C. gave, in grams per ton:—

SiO_2	22.6	
Fe_2O_3	7	
Ca O	147.6	
Mg O	58.6	
Na_2O (48.6 Na)	65.5	
Cl	107.21	
SO_3	32.4	
CO_2	138.1	
		579
Total solids	680	
Loss on ignition (organic)	130	
		550
Inorganic matter present.		
Difference (O of Na_2O and Fe_2O_3)		29

This may be combined in various ways, for instance as:—

Calcium sulphate	54.9
Calcium carbonate	223.6
Magnesium carbonate	52.3
Sodium chloride	78.2
Sodium silicate	45.7
Magnesium chloride	78.6
	546.

This well is in the coal measures, and the presence of sulphates is significant, but the water is peculiar and has a peculiar history. It is 62 feet to bed rock and 115 feet deep. But it is only 125 feet from the Downey House well which was put down 740 feet in hope of a flow. None was obtained, but it grew salty. So it was plugged at 72 feet. When the Piatt well is not pumping the Downey well[1] stands about 22 feet below the ground level, but when the Piatt well began to pump it dropped. The first of the year the Piatt well was not salt, but lately it has been so, as they are using it hard. It can give 17,000 gallons an hour, and they have used as much as 6,000 pounds. Evidently the Piatts are drawing from the Downey well below the plug.

A well at 1316 Washington avenue south, gave Prof. Kedzie:—

	Grams per litre.
Total solids	565.6
Organic	96
Inorganic	469.6
Chlorine	37.2
Sodium chloride	61.5

This was only between 30 and 100 feet deep.

[1] Proc. A. A. A. S. 1875.

The Kennicott Water Softener Co. have sent us the following analyses, obviously of rather shallow waters, though we do not know the exact source. Those at Midland and Benton Harbor are nearly saturated with incrusting solids.

Analysis of Water from Midland.

	Parts per million.
Calcium carbonate	126
Calcium sulphate	32
Calcium chloride	2
Magnesium carbonate	43
Magnesium sulphate	9
Magnesium chloride	9
Sodium sulphate	0
Sodium chloride	17
Sodium carbonate	0
Oxides of iron and alumina	3
Carbonic acid	78
Silica	62
Alkalinity	160
Suspended matter	29
Incrusting solids	237
Non-incrusting solids	17

Analysis of Benton Harbor Water.

Kennicott Water Softener Co., 1363, March 11, 1902.

	Parts per million.
Calcium carbonate	101
Calcium sulphate	18
Calcium chloride	trace
Magnesium carbonate	19
Magnesium sulphate	41
Magnesium chloride	0
Sodium sulphate	0
Sodium chloride	10
Sodium carbonate	0
Oxides of iron and alumina	2
Carbonic acid	8
Silica	6
Alkalinity	140
Suspended matter	37
Incrusting solids	224
Non-incrusting solids	10

Analysis of Niles Water.

Kennicott Co. 1396. Apr. 19.

		Parts per million.
$Ca\ CO_3$	4.02	69
$Ca\ Cl_2$	.....	.....
$Ca\ SO_4$	0.50	10
$Fe_2\ O_3$	0.05	1
$Mg\ CO_3$	1.57	27
$Mg\ Cl_2$	.....	.....
SO_3	0.47	8
$Na_2\ CO_3$	1.91	33
$Si\ O_2$	0.13	2
Na Cl	trace	.....
Na	0	.....
CO_2	1.28	2
Alk.	8.16	140
Sulp.	0	.....
Incrust.	6.74	116
Non-incrusting solids	1.91	33

A report (Omaha Bee, Sept. 8, 1901) that there was a large amount of lithia found in a stream flowing into Little Traverse Bay by Prof. Kedzie was a mistake.

The following analysis by Prof. R. C. Kedzie of Carrier creek near Grand Rapids is also a typical hard water, but little more than saturated. There must be free carbonic acid and calcium sulphate in excess.

Calcium carbonate	160
Calcium sulphate	35
Magnesium carbonate	91
Soluble $Si\ O_2$	29
Sodium (and potassium) chloride	28
	315
Organic or loss	14
Total	329

Hardness 16°.

S. O. Hickok at Allen, Hillsdale county, Michigan, has a well which yields:—

	Grams per gallon.
Sodium chloride	277.04
Calcium sulphate	33.04

In Saginaw recently[1] a well was put down in "middle ground," a former island in Saginaw river, to test the probabilities as a water supply.[2] The longer it was pumped the saltier it got as appears from the fol-

[1] Saginaw Courier Herald 2:26:1903, 3:25:1903, 8:26:1903, 8:27:1903.

[2] It passed through lumber mill waste and salt, and at 12 feet river sand and then clay, then at 42 feet into fine gravel and then from 44 to 53 feet coarse gravel.

lowing tests, and it is apparent that the shallower wells in Saginaw are likely to have more or less admixture of salt from the abandoned salt wells whose casings have rusted.

The following analyses were made by Heim Bros., reduced to parts per million.

June.	10	11	15	16	17	19	20
(Sodium) chloride	1,370	1,399	1,285	1,285	1,287	1,329	1,343
Total solids	2,630	2,809					
Hardness[1].....			77°	77°	84°	87°	80.5°

It may be worth while to include a few typical analyses of deeper waters, which may be classed as mineral waters or brines. I have spent some time in studying analyses of a large series of brines of the Napoleon series, analyzed by Hahn, but these have already been published, though in German. An analysis as yet unpublished, is the following, of the brine at St Charles, at a depth from 700 to 810 feet.

The statement is worked up by me from figures by A. N. Clark.

		Parts per thousand, grams per kilogram.
$Ca\ Cl_2$		48.100
$+2\ H_2O$	14.68	
$Ca\ SO_4$		.884
$+2\ H_2O$	.232	
$Mg\ Cl_2$		7.620
$Mg\ Br_2$		.200
FeO		.259
$Fe_2\ O_3$		.196
Balance chlorine as NaCl.....		222.460
		279.719
Water of crystallization.....		14.912
Solids by summation.....		294.631
Solids by evaporation.....		295
Specific gravity		1.183

This is a typical Marshall water, high in earthy chlorides, and low in sulphates. The North American Chemical Co. brine runs 40.3 $Ca\ Cl_2$ and 16 $Mg\ Cl_2$ with only .874 $Ca\ SO_4$.

The next important brine below, that of the Berea, is different, being very much freer from calcium magnesium chloride. This may be connected with its being isolated in a greater series of shales fairly free from lime and magnesia. The strata are also quite salt even close to their outcrop. For instance Mr. Cobb made the following determinations on a brine from Jason & Shumway's test well for oil:—

Sp Gr = 1.1426

Cl = 11.54

As sodium chloride 19.18% NaCl which would imply Sp. wt. 1.1441. Dow reports Sp. Gr. 1.139 and Br = .033 or $Mg\ Br_2$ = .0395.

[1]The hardness is probably largely sulphates as well as carbonates.

Microscopic examinations of an evaporated drop shows no Ca SO_4 nor (Ca Mg) Cl_2, and there is no excess of specific weight over that of pure Na Cl solution which there would be the (Ca Mg) Cl_2 admixture appreciable. The refractive index is five times farther from that of water than that of saturated brine. This well is recorded below.

The next brine in order is that of the Dundee or Corniferous.

The following is an analysis of a sample from this horizon at Assyria:—

Sp. Gr. ..... 1.1955=25.26% salt if all salt.

	Per cent.
Br	0.11
CaO	4.4
MgO	1.076
Cl	14.65

Whence

	Parts per thousand.
Ca Cl_2	87.02
Mg Cl_2	24.67
Mg Br_2	1.27
NaCl	119.66
	237.62

Laboratory of Prof. E. D. Campbell, E. E. Ware, Analyst.

Spectroscopic examination revealed strontium, bromine and lithium, and faintly perhaps barium. The presence of barium and strontium accounts for the absence of sulphates. No H_2S was noticeable, but the sample[1] also contained 1.044 grams of undissolved matter, chiefly calcium carbonate and clay, as the sample was taken while work was going on.

From the Company we have the following analysis of the Dundee or Corniferous water at Port Huron.

This is a new well 750 feet deep and said to be 100 feet in solid rock, i. e., Dundee. Compare Grand Trunk well on p. 277, Report for 1901.

Port Huron, Mich., July 8th, 1902.

From the analyses of Dr. E. Ristenpart, analytic chemist, of Patterson, N. J., and Prof. Kedzie of the Michigan Agricultural College, we obtain the following as the constituents of the Deep-spring Mineral Water:—

[1]40cc.

DEEP SPRING MINERAL WATER, PORT HURON.

	Parts per 1000.
Chloride sodium	66.6832
Chloride potassium	2.8181
Chloride ammonium	0.1431
Chloride calcium	5.2492
Chloride magnesium	6.7846
Bromide magnesium	0.0488
Iodide magnesium	0.0003
Bicarbonate calcium	1.7600
Bicarbonate iron	0.0140
Sulphate calcium	3.7721
Hyposulphite sodium	0.0177
Hydrosulphate sodium	0.0136
Carbonate sodium	.....
Lithium chloride	.....
Alumina	0.0033
Silica	0.0085
Sulphuretted hydrogen gas	0.3146
Carbonic acid gas	0.7147

WATERS OF THE UPPER PENINSULA OF MICHIGAN.

BY A. C. LANE.

As I mentioned in my last annual report, my papers on the water supply being absolutely exhausted, an early duty should be to cover the ground again in a fuller way, either under State or United States auspices, but I have not got around to it. I have, however, prepared a brief abstract of the situation as to water supply in the Upper Peninsula for Mr. Alfred R. Schultz, who is working that region in connection with Wisconsin for the U. S. Geological Survey, and we have also compared notes on the Marinette, Menominee, and similar wells. I have also had some correspondence with S. Weidman of the Wisconsin Geological Survey in the matter, and with W. C. Alden, who is working on the stratigraphy for the U. S. Geological Survey. We have agreed quite fairly well in our correlation of things, and as it means a rather closer correlation of the Michigan and Wisconsin strata it may be well to give the records in connection with the hydrography, as that appears to be their greatest importance, though they also have economic interest in connection with oil, shale and limestone questions.

The Upper Peninsula is well supplied with water. Fig. 5 of Water Supply Paper No. 30 shows that the precipitation is mainly between 30 and 35 inches; a very large proportion is snow (page 49), which is often four or five feet deep on the level, and very markedly affects the mean annual soil and well temperatures.[1] The latter are 43° or over, the former 40°.

The long series of analyses of the Marquette City water supply, by Vaughan,[2] give a good idea of the Lake Superior waters and its variations practically, and should be compared with the analysis of Lake Superior water far from land, given fully in Water Supply Paper No. 31, which is in brief as follows:—

Lake Superior Water, by W. F. Jackman.[3]

At 27° C. Sp. Gr. 1.0004.

	Grams per metric ton.
SiO_2	8.53
Al	.48.
Fe	.69
Ca	12.80
Sr	1.34
Mg	2.78
CO_3	22.23
SO_4	3.73
B_2	trace
Na	3.18
K	very faint trace
Cl	2.43
N_2O_6	.77
Sum	58.96

[1] Page 246 Annual for 1901.
[2] Numbers 254, 261, 281, 297, 298, 301, 302, 303, 289, 306, 308, 317, 325, 327, 330, 339, 340, 344, 346, 347, 350, 352, 355, 256, 268, 360, 362, 366, 368, 374, 378.
[3] Taken in the summer of 1886, about 50 miles from Keweenaw Point and 50 feet below the surface.

Total residue	69.97
Inorganic residue	57.61
Loss on ignition	12.36
Free ammonia	.061
Albumenoid ammonia	.12
Oxygen consumed	1.77
Hardness temporary in grams per ton	48.57
Hardness permanent in grams per ton	38.28

ANALYSES OF MARQUETTE CITY WATER SUPPLY (LAKE SUPERIOR).

BY VICTOR C. VAUGHAN.

Number.	2544	2615	2816	2977	2988	3019
Date	3/21/95	5/24/95	7/27/95	12/17/95	1.17.96	2 17 96
Color[3]				Dirty yellowish		
Odor[3]				Musty	Slightly musty	
Reaction	alkaline	alkaline				
Hardness[1]	3°	3.4	2°	3°	2.9	3
Total residue	68	60	100	190	160	190
Inorganic residue	34	10	90	60	110	60
Organic residue	34	50	10	130	50	130
Cl as NaCl	8.25	5.775	2	4.1	4.125	4.1
Potassium permanganate reduces			2			
Free ammonia	0.01	.0094	0.005	0.006	.048	0.006
Albumenoid ammonia	0.076	.05	0.001	0.120	.132	0.120
Nitrates		faint tr.		trace		trace
Nitrites						
No. of bacteria in 72 hours[2]	500	Liquefaction	72	325	Liquefaction	325

[1]Degrees of hardness are number of grains of calcium carbonate per U. S. gallon that could produce an equivalent hardness, i. e., each degree of hardness is equivalent to about 17 grams per metric ton of calcium, magnesium and ferrous carbonates.

[2]The result of inoculation was in all cases negative; no pathogenic bacteria were discovered.

[3]Colorless and odorless unless otherwise stated.

[4]Vegetable debris (sawdust, etc.) bacteria, diatoms.

[5]Microscope shows small inorganic deposit. The hardness and amount of Cl show an error in the amount of inorganic residue.

[6]Trace of sulphates, vegetable fibres.

[7]Inorganic matter and vegetable debris.

[8]Microscope shows deposit of inorganic matter.

[9]Microscope shows deposit of inorganic matter and vegetable debris.

ANALYSES OF MARQUETTE CITY WATER SUPPLY.—CONTINUED.

Number.	302	303	2891	3062	3083	3174	3255
Date	2 18/96	2/18/96	10/22/95	3/7/96	4/21/96	5/16/96	6/18/96
Color							
Odor							
Reaction			alkaline	alkaline		alkaline	alkaline
Hardness			3°	3°.8	4°	6°	5
Total residue			60	60	184	70	90
Inorganic residue			50	20	69	40	40
Organic residue			10	40	115	30	50
Cl as NaCl			3.30	3.25	6	3.30	4
Potassium permanganate reduces							
Free ammonia			0.02	.048	0.03	0.040	0.05
Albumenoid ammonia			0.008	.14	0.1	0.03	0.02
Nitrates			traces	trace			
Nitrites					trace		
No. of bacteria in 72 hours			Liquefaction	150	Liquefaction	Liquefaction	120

[1]Trace of sulphates.
[2]Microscope shows little inorganic matter.
[3]Trace of sulphates, U. M. dead insect, vegetable debris, inorganic matter.
[4]Trace of sulphates, very small deposit.
[5]Trace of sulphates, small indeterminate granules.

ANALYSES OF MARQUETTE CITY WATER SUPPLY.—CONTINUED.

Number.	3271	3302	3395	3404	445	3466	3477
Date	8/1/96	8/22/96	9/26/96	10/29/96	12/3/96	12/21/96	11/24/96
Color							Milky-Opalescent
Odor							Marked
Reaction							
Hardness	3	5	3.5	3.7	3.4	3.5	4.5
Total residue	90	120	100	75	57	66	77
Inorganic residue	81	105	80	46	32	44	18
Organic residue	9	15	20	29	25	22	59
Cl as NaCl	1.65	8.25	6.0	13.28	6.6	6.6	8.25
Potassium permangana e reduces	1	2	1+	2—	2	2—	4—
Free ammonia	0.006	0.008	0.0066	0.012	0.0066+	0.0004+	0.104
Albumenoid ammonia	0.04	0.0106	0.0133	0.0266	0.0480	0.0024	0.094
Nitrates				trace			
Nitrites		trace					
No. of bacteria in 72 hours.	78	310	80	Liquefaction	Liquefied	17	Liquefaction

[1]U. M. small amount of vegetable fibres.
[2]Trace of sulphates; small amount of vegetable debris.
[3]Very small amount of organic debris.
[4]Small amount of vegetable debris.
[5]U. M. small deposit, desmids, diatoms and debris.
[6]U. M. very small amount of vegetable matter.
[7]Large amount of deposit; infusoria, Vorticellæ, paramœcium, Uvella glaucoma, diatoms, ova, algæ debris.

ANALYSES OF MARQUETTE CITY WATER SUPPLY.—CONTINUED.

Number.	350[1]	352[1]	355[1]	356[1]	358[2]	360[1]
Date	1/26/97	2/25/97	3/24/97	4/22/97	5/20/97	6/22/97
Color						
Odor						
Reaction						
Hardness	3.5	3°	4°.5	4°.2	3°.5	3°.5
Total residue	92	73	92	62	75	102
Inorganic residue	52	48	60	47	53	70
Organic residue	40	25	32	15	22	32
Cl as NaCl	8.25	8.25	8.25	6.6	6.6	6.6
Potassium permanganate reduces	2—	2—	2—	2	2	2+
Free ammonia	0.0026+	0.0023	0.0106+	0.004	0.0053	0.003
Albumenoid ammonia	0.0133	0.0154	0.0186+	0.0213+	0.0176	0.0084
Nitrates			trace			
Nitrites			trace			
No. of bacteria in 72 hours	Liquefaction	Liquefaction	Liquefaction	Liquefaction	Liquefaction	Liquefaction

[1]Small amount of vegetable matter.
[2]Very small amount of organic debris.

ANALYSES OF MARQUETTE CITY WATER SUPPLY.—CONCLUDED.

Number.	362[1]	366[1]	368[1]	374[2]	378[3]
Date	1/27/97	8/25/97	9/25/97	10/29/97	11/22/97
Color	.....	.....	.....	.....	.....
Odor	.....	.....	.....	.....	.....
Reaction	.....	.....	.....	.....	.....
Hardness	3°	3°.5	3°.7	3°.5	3°.2
Total residue	217	190	188	180	94
Inorganic residue	156	152	148	148	70
Organic residue	61	38	40	32	24
Cl as NaCl	3.3	6.6	6.6	5.	4.95
Potassium permanganate reduces	2—	2—	2—	1.57	2+
Free ammonia	0.003	0.012	0.016	0.015	0.0133
Albumenoid ammonia	0.015	0.06	0.072	0.056	0.0106
Nitrates	trace	.....	.....	.....	.....
Nitrites	trace	.....	.....	.....	.....
No. of bacteria in 72 hours	170	340	630	5	36

[1]Small amount of organic debris.
[2]Few vegetable fibres.
[3]Very small amount of organic matter.

We see that it is usually clear and odorless, but occasionally in the winter it becomes turbid and foul (analyses 297, 347), or musty.

The reaction is alkaline quite frequently.

The hardness of 3°, rarely over 4°, shows how soft Lake Superior water is relative to that of Lake Michigan.[1]

The total amount of solid residue *may* run up to 200 grams a metric ton in winter, when the organic matter accumulates under the ice, but usually is nearer 60 to 80, as in Jackman's analysis. The inorganic part of this is ordinarily 40 to 60 grams per metric ton, a minute quantity, which the hardness shows must be mainly calcium magnesium carbonates.

The chlorine estimated as sodium chloride varies from 3 to 6 grams per ton. These figures agree with that of the pure Lake Superior water, and show that on the whole the only difference is a varying amount of harmless organic matter, possibly due to sawdust.

To compare with the analyses of Lake Superior water in mid lake and at Marquette, we have the following of Lake Superior from the Calumet supply, Calumet and Hecla pumping plant, G. L. Heath analyst.

It agrees very fairly considering the minute quantities in most constituents, though as the quantities are so minute, relatively large errors may be due to impurity of chemical. The variation in the amount of strontium and potassium may be due to inadequacy of analytical methods. The total amount of "incrusting solids," that is the sulphates and carbonates of the earths is in Heath's and Jackman's analysis about the same—42.06 respectively 46.88 part per million.

[1]See analyses of Menominee Supply Nos. 250, 251, 309, 315, and those given in Water Supply paper No. 30, etc.

	Lake Superior, Jan. 6, 1903. Per million.
Suspended sediment	9.8
Iron and aluminum oxide	1.1
Calcium sulphate	2.0
Calcium carbonate	29.3
Magnesium carbonate	11.3
Sodium chloride	2.7
Potassium chloride	1.6
Difference organic, etc.	1.8
	63.9

The other Great Lake, the Green Bay Arm of Lake Michigan, is best illustrated by the Menominee Water Works analyses in the table below:—

GREEN BAY, LAKE MICHIGAN, MENOMINEE WATER WORKS,

ANALYZED BY V. C. VAUGHAN.

Color, odor, nitrites and reaction from inoculation none, unless so stated.

Number.	250[1]	251[1]	309	310[3]	311[4]
Date	2 2 95	2 2 95	4,27,96[2]	4,27,96	4 27 96
Reaction	alkaline	alkaline	alkaline	alkaline	alkaline
Hardness	8°	8°	9°.6	9°.5	9°.6
Total residue	260	250	147	150	147
Inorganic residue	190	200	100	100	100
Organic residue	70	50	47	5	47
Cl as NaCl	1.65	1.65	6	6	6
Free ammonia	.002	.004	0.01	0.01	0.013
Albumenoid ammonia	.06	.059	0.052	0.052	0.060
Nitrates	Faint trace	Faint trace	.....	.....	.....
No. of bacteria in 72 hours	Liquefaction	Liquefaction	90	750	100

[1]Trace of sulphates.
[2]U. M. shows some inorganic matter and vegetable debris.
[3]Large deposit of inorganic matter, unicellular animals and plants and vegetable debris.
[4]Small deposit.

GREEN BAY, LAKE MICHIGAN, MENOMINEE WATER WORKS.—CONTINUED.

Number.	312[1]	313[2], 314[2], 315[3].
Date	5/2/96	5/2/96
Color	Brownish and cloudy	Slightly brown cloudy
Reaction	alkaline	alkaline
Hardness	7	9+
Total residue	170	150
Inorganic residue	90	100
Organic residue	80	50
Cl as NaCl	6+	6
Free ammonia	0.08	0.009
Albumenoid ammonia	0.10	0.095
Nitrates	.....	.....
No. of bacteria in 72 hours	Liquefied	Liquefied[3]

[1]Considerable deposit of inorganic matter, vegetable debris, infusoria.
[2]Considerable deposit of inorganic matter and vegetable debris.
[3]Result of inoculation in 314 +, in 313 and 315 negative.

The hardness, it will be noticed, is twice that of Lake Superior, and not unlike the analyses of Lake Michigan, given in Water Supply Paper No. 31. It may be taken, then, as very nearly that of Lake Michigan.

It is interesting and important to notice that it is *not* as soft as many of the artesian wells of the same region, so that the frequent objection to artesian waters, that they are extra hard, does not apply here. The extra hardness of the Lake Michigan water shows even in the ice, the following two analyses being made from examples of ice sent from Ishpeming, one from Teal Lake, near by, and one from Lake Michigan. It is obvious that much of the hardness has been frozen out, but not all.

ICE ANALYSES.

BY V. C. VAUGHAN.

Samples from Ishpeming, No. 171, from Teal Lake, No. 172 from Lake Michigan.

Number.	171[1]	172[2]
Date	4 18 93	4 - 93
Reaction	Slightly acid	Slightly acid
Hardness	1.0	2.0
Total residue	10.0	29.0
Inorganic residue	6.0	0.00
Organic residue	4.0	29.0
Cl as NaCl	0.2	0.8
Free ammonia	0.10	0.10
Albumenoid ammonia	0.06	0.06
Nitrates	.05	0.2
Nitrites	trace	.....
No. of bacteria in 72 hours	19,400	3888

[1] U. M monads and bacteria. See p. 148.
[2] U. M. shows bacteria.

The conditions are favorable for artesian wells throughout nearly all the area of the Paleozoic rocks in the eastern half. The dips are southerly and the divide is generally close to Lake Superior, so that flowing wells from bed rock may be expected along the Lake Michigan shore and up all the river valleys for a width varying according to the surface and rock topography. Artesian wells of this sort occur at Menominee, Escanaba, Gladstone, Rapid River, Manistique, St. Ignace, Newberry, and numerous other points. Notes concerning some of these are as follows:

At Menominee, Hon. S. M. Stephenson has put down at least two deep wells. The character of the water is probably shown by Vaughan's analyses Nos. 328 and 331. Back of the S. M. Stephenson house there was one put down in 1895-6, from 500 to 1,000 feet deep. The well started in the Trenton limestone and is said to obtain its water from a sandstone, probably mainly Potsdam. Though the analyses could not be found for me at Menominee, and it is said to contain much magnesia, I suspect that analysis No. 328 may be of it. I also think it possible that in dealing with unusually large quantities of salt for potable waters, the decimal point has been misplaced, for the total solids are disproportionately large. The head is 15 feet and the temperature 55½° F., by Ther. No. 7536. Another well three miles west from No. 1, upon his farm, is 720 feet deep and 30 feet above the lake. The head is only one foot above the surface and the water is too hard for boilers. It starts in the Trenton, passes through some "slate and also white stuff and black slate." There was 60 feet of pipe, which may be to bed rock. Water was encountered at various levels, but a distinctly larger quantity at 620 feet. This may of

course be a fissure in the Lower Magnesian or Calciferous, but is I think not far from the top of the Potsdam, and the base of the well may have reached the Archean. This may be represented by analysis 331.

MENOMINEE ARTESIAN WELL.

Number.	328	331[2]
Date	8/1/96	8/24/96
Reaction	Slightly acid	
Hardness	4°	8°
Total residue	2050	2054
Inorganic residue	1798	1783
Organic residue	352	271
Cl as NaCl	18.15	18.15
Sulphates	87 2	88.42
Potassium permanganate reduced	1	1
Free ammonia	0.0746	0.012
Albumenoid ammonia	0.0906	0.008
Nitrates	Trace	
Nitrites	Trace	
No. of bacteria in 72 hours	1260	8

[1]Result of inoculation positive, but it can hardly be due to bacterial contamination. It merely shows that this particular mineral water was not good medicine for the rabbit. The date renders it pretty certain that it is one of Mr. S. M. Stephenson's wells. L.
[2]Result of inoculation negative.

These analyses should be compared with that of the well of Hon. Isaac Stephenson, close by just over the Wisconsin line, which has, however, a much lower temperature, and hence probably a shallower source, though the surface piping may be in part responsible.

"Following the usual method of expressing the results of water analysis, the constituents have been grouped as follows":—[1]

	Grams per metric ton.	Grains per gallon.
Sodium chloride	119.50	7.649
Potassium sulphate	20.46	1.193
Calcium sulphate	727.60	42.432
Magnesium sulphate	182.34	10.634
Aluminum sulphate	47.27	2.757
Magnesium chloride	69.51	4.054
Magnesium bicarbonate	52.75	3.076
Ferrous bicarbonate	9.48	0.553
Silica	5.20	0.303
Sulphuretted hydrogen, not determined.		
	1,184.11	

[1]University of Wisconsin Chemical Laboratory. Compare Geol. of Wis. II, p. 153.

There is one thing common to the Menominee and Marinette artesian well analyses. In both the sulphates seem to predominate over the chlorides. Yet they probably do not represent water from exactly the same horizon. The Marinette Stephenson well, drilled in August, 1895, at the house of Hon. Isaac Stephenson, passed through lime rock and dolomite, and a little light and reddish sandstone (St. Peters? not much) and narrow strata of slate for the first 200 feet. Water was first struck in a crevice in the Lower Magnesian at 405 feet, with quite a flow. Then, at 410 feet, there was a big crevice, with a drop of four feet, which broke the cable, and the water has a greater flow, and 21 feet head. Below this[1] there was no increase in water, though they went down to "granite" at 716 feet, passing largely through "limerock" (dolomite). No water, that is no additional water pressure, was encountered below 415 feet and a rubber plug was put in at 457 feet, and the pipes go down to 415 feet, so that in the I. Stephenson well we have a water purely from that level, the Lower Magnesian, or Calciferous dolomite. This is more than we can be sure of in other cases. Mr. Stephenson reported the temperature at 49°, I made it 50.°5. There are a number of other wells which flow or have flowed in Marinette.

A well at Oakwood, three and a half miles south of the town, is said to be 999[2] feet deep. A sample at 860 feet is a white sand, while one at 920 feet contains much feldspar, broken quartz fragments, etc., and is of a reddish color. Let run a few moments the temperature is 53°.

A well for oil and gas, two miles south of Stephenson's, put down in 1902-3, by a company of which Mr. H. B. Simcox was manager, may have reached the Precambrian at 850, where there was a change from white sand to red, the record being:—

Drift to bed rock.....	70	70
70 ft. 10-inch casing.		
(Trenton?). Very hard rock.....	300	370

150 ft. 8-inch casing, 450 ft. 6-inch casing; water at about 400, 500 and 600 feet.

(Calciferous?). Various layers, including "hurry up sands," which occur in beds a few feet thick, soft, but cutting the drill and themselves light, mixed with hard layers.

(Potsdam?). At end, white sandstone; bottom, red sand (granite?).

The temperature of a mixture of all the flows was 51.°8. Probably the plug in the Stephenson well cuts off a little warmer water from below.

Mr. A. C. Merriman also has two or three wells, the one at his house being 719 feet deep.

From a well at the water works, samples have been preserved, and the following are my notes of inspection, with the interpretation put on them, after consultation with S. Weidman, Alfred R. Schultz and Wm. C. Alden. Mr. Schultz writes that the records obtained at Marinette this summer all indicated that the St. Peters is not represented, although no first-class record and samples were available. Mr. Alden wrote to Dr. Weidman a letter given below, and various letters to me afterwards, the substance of which is that in a number of wells like the above the

[1] A still more recent record with samples kept by the kindness of Mr. H. B. Simcox, shows the St. Peters sandstone well marked from 325 to 400 feet, so that the I. Stephenson well probably draws from that horizon.

[2] An error of an even hundred feet the depth of the well and the sample is to be suspected.

question is whether the St. Peters is absent and the limestone dolomite series to be divided between the Trenton and Lower Magnesian, or whether the erosion which he supposes to have taken place at the end of the deposition of the Lower Magnesian may not have cut it away entirely, so that the whole limestone series should be referred to the Galena-Trenton. In order to understand the question, the following abstract of the different strata of Eastern Wisconsin, compiled from Volume II of the Wisconsin reports, is given.

EASTERN WISCONSIN SECTION.[1]

HAMILTON, argillaceous limestone, page 395. Cement rock, fossiliferous.

Unconformity.

LOWER HELDERBERG (Monroe), p. 390, hard, brittle, angular, acicular or dark dolomite, laminated with alternating light and dark bands.

Unconformity.

	Feet.
NIAGARA, p. 335	719-450
White dolomites, generally very little impurity, divided into:	
1. Guelph, like Racine but different in fossils.	
2. Racine, buff, gray or blue granular, fossiliferous—9 ft. thick below, rough.	
3. Upper Coral; thin bedded buff or bluish, fine, with chert and druses, splitting, very fossiliferous	45-70
4. Lower Coral beds (p. 348). Massive, rough, with layers cherty or argillaceous or like the Byron, full of *Favosites* and brachiopods.	
5. Byron, white, smooth, fine, pure, mudcracks and ripple marks, tinged with gray or pink, conchoidal fracture	110
6. Mayville, rough, coarse grained, fossils ill preserved.	
1. Brecciated, vertical fissured	60-100
2. Even bedded white, pure, often porous, granular.	
3. Brecciated, cherty, gray	5-35
4. Hard heavy bedded, vertical fissures	6-12
5. Shaly impure, yellow to greenish	4-10
CLINTON. Irregular lens like masses of iron ore	0-
Unconformity beneath. Lorraine and Utica often in contact.	
CINCINNATI (Lorraine & Utica), clayey shales and limestones, p. 315	240
Blue green, fine or impure, with fossiliferous grits, grading to limestone, sometimes sandy.	
GALENA, lime and dolomite, impure, crystalline granular dolomite; greenish blue and often non-fossiliferous, impure earthy —*Murchisonia major*, more shaly to the N.	160
TRENTON subdivided into	53
1. Upper blue 1. Upper blue bed; *Lept. sericea*, Brachiopods *Bryozoa*, & *Chætetes*	15
2. Upper buff bed (p. 296); *Cyathophyllum*, lamellibranchs	55

[1]Chamberlin Geol. Wis. II Van Hise, Ore Deposits, p. 397.

Feet.

2. Lower buff dolomite. 3. Low blue beds dolomite, cherty, blue green, thin impure, carbon, corals 25
4. Low buff beds, earthy yellow crystalline 25

ST. PETER'S sandstone (p. 286-289) 0-212
Well rounded incoherent quartz grains light colored, laminated, cross bedded, iron ore nodules at top.

Probable erosion interval possibly the line between Cambrian and Silurian.

LOWER MAGNESIAN (CALCIFEROUS), p. 268, granular dolomite, with 2-10% disseminated silica, chert nodules, quartz geodes and a little sand, sometimes oolitic, with some sand centers, irregular, at times brecciated. 62-141
Top eroded and very uneven, bottom even. Fossils very rare.

POTSDAM (p. 260).

1. Madison sandstone 35
   Typically coarse grained, thick bedded, but soft, slightly calcareous, light colored 60
2. Mendota limestone,
   Alternating sandy dolomites, sandy calcareous shales, and shaly calcareous sandstones. The dolomites are soft, granular, porous, thin bedded, buff colored with frequent sand seams. The shales are variegated yellow and red and characteristically purple, mottled, soft brittle, readily weathered. The sand stones are either white, buff yellow or orange calcareous, or a glauconitic green sand. Upper and lower limits ill defined.
   Dr. Owen's fifth trilobite bed and *Dicellocephalus minnesotensis, D. pepinensis, Lingula aurora, L. mosia, Lingulepis pinniformis, Illænus quadratus.*
3. Light colored sand stone, mainly quartz, slightly calcareous, a little chert, limestone and granite.
4. Blue green shale, micaceous, calcareous.
5. Light colored quartz and sandstone.
6. Coarse non-calcareous sandstone with large grains of transparent light colored quartz.

Mr. Alden is inclined to accept the possibility of a suggestion which had independently occurred to me that the base of the deep Sheboygan well might be in the Potsdam, in which case the same may be true at Oshkosh and Marinette, and the Lower Magnesian also absent. On the whole, however, I am inclined to accept the older interpretation of Chamberlin as more likely to be right, as I think that the Potsdam water is not so hard and is not so much sulphated as the waters above.

MARINETTE WATER WORKS WELL.

The record of the manager, W. S. Kulm, through Mr. Schultz, is:—

Drift.	Thickness.	Total.	Comparison.
Surface sand gravel	70	70	S. 70
Galena and Trenton—			
Gray limestone	10	80	S. 80, S. 85.
Soapstone and limestone	64	144	
Soapstone	52	196	S. 144
Soft limestone	44	240	S. 196
Hard gray limestone	10	250	S. 240
Slate and limestone	70	320	S. 250 ("slate". Gladstone 327 to 404
Soft flaky limestone	134	450	S. 320
Very hard limestone	100	550	S. 450
Potsdam—			
Hard yellow sandstone	10	560	Gladstone 642
Gray limestone	20	580	
S. 550, 560 and 580 possibly mixed—			
Gray sandstone (small flow)	90	670	
White sandstone	46	716	S. 670 Gladstone 743
Reddish granite			S. 712, S. 716

S. Stand for sample.

My notes on the samples are:—

Pleistocene—
70—red sand and gravel.
Galena?
80, 85—chipping limestone.
Trenton?
144—blue shales (compare 481 at Wagner's well).
196—coarse chipping limestone.
240—chipping limestone.
250—"slate" light blue and white.
St. Peter's sandstone absent or ignored, according to Alden.
Lower Magnesian=Calciferous.
320—chipping limestone, coarse.
450—coarse chipping, light colored limestone and dolomite.
Potsdam?
550—very white looking marly calciferous sandstone.
560—unwashed white calciferous sandstone.
560—white and greenish calcareous sandstone.
670—white sand.
685, 700—rounded white sand.
Archean.
712—"granite" broken and loose.
716—dark red quartzite (also quartz).

Mt. Vernon, Ia., Nov. 5, 1903.

Dr. Samuel Weidman,
Wisconsin Geological Survey, Madison, Wis.:

My Dear Dr. Weidman—Your favor of the 3d inst. enclosing letters and well records from Mr. Alfred C. Lane is received.

In regard to the treatment of the Calciferous formation in Wisconsin, my observations in the southeastern part of the state have been entirely confirmatory of those of Dr. Chamberlin and his associates as presented in Volumes I and II of the Geology of Wisconsin, where the subject is fully discussed. As you know, the Lower Magnesian limestone, which has been regarded as the equivalent of the Calciferous of the east, is not a sandstone at all here, but a hard, gray, rough-textured dolomite carrying much chert and crystallized quartz. On the other hand, the St. Peter sandstone, which has been regarded by some as the equivalent of the Chazy limestone of the east, is here a loosely coherent, quartz sandstone, with rarely more than a slight calcareous cement, and that not always present. The lower part of this formation in many places is reddish and not infrequently is somewhat shaly. This has been noted at several places to the south and east of Madison. In the shaft of the Waterloo "iron mine," east of Madison, I found this summer above the typical Lower Magnesian limestone, the following beds, which I am inclined to regard as belonging to the lower part of the St. Peter group, though it is possible that they really belong with the underlying Lower Magnesian limestone:—

Interstratified buff and purplish rock, varying from a calcareous sandstone to a sandy limestone	3	feet
Fine grained, buff, arenaceous limestone	2	"
Similar bluish, fine grained rock, with fine grains of green color (green sand?) disseminated throughout, said to be shaly	4	"
Fine grained buff dolomite and shale, somewhat variable in character	18	"
Red and purplish arenaceous shale	6	"
Interbedded, thin layers of buff limestone and purplish limestone, shaly in part	4	"
	—	"
These thicknesses are only approximte, the total being	33	"
Below this is the typical, rough textured, cherty, brownish-gray Lower Magnesian limestone, decidedly different in character from the above	28½	feet

I have not found any limestone layers in the lower part of the St. Peter group except in this locality. It may be that these correspond to the "Lime and sandstone in mixed layers," which Mr. Lane reports between the depths of 325 and 404 feet in the St. P. & Ste. Marie R'y [Gladstone] well record which you sent.

I think it not strange that we should find in Michigan that the St. Peter sandstone is not developed so well as in Wisconsin. We would expect to find a gradual change in both this and the Lower Magnesian to the types developed farther east. Some such change occurs in the later formation on going southwestward into northeastern Iowa, though the St.

Peter sandstone continues above it. In the Geology of Allamakee county (Iowa Geological Survey, Vol. IV., pp. 61-71), Prof. Calvin discusses these formations under the name of Oneota limestone and St. Peter sandstone. He says (p. 63-64) :—

"The last fifty or sixty feet in ascending towards the St. Peter sandstone are characterized by the presence of beds of sand and shale interstratified with the Magnesian limestone. The sandstone layers, as already noted, differ as to number and position in different localities, and it is not possible to recognize any one as sufficiently constant to mark a definite horizon. It is in the last 50 or 60 feet that the Iowa equivalents of the New Richmond sandstone and the Willow River limestone of Wisconsin, or the New Richmond sandstone and the Shakopee limestone of Minnesota, are found."

On page 68, Prof. Calvin states that there can be little doubt as to the essential equivalence of the Lower Magnesian (Oneota) limestone and the Calciferous sandrock of New York and Vermont, both on stratigraphical and paleontological grounds. He says:—

"The relations of the Calciferous sandrock of the Champlain valley are paleontologically more intimate with the overlying Trenton than with the underlying Potsdam. The formation belongs to the Ordovician or Lower Silurian, and not to the Cambrian, and the same statement may be made with respect to its equivalent, the Oneota limestone in northeastern Iowa."

Concerning the taxonomic relations of the St. Peter sandstone, he states that Sardeson gives a list of fossils from the St. Peter sandstone near Minneapolis, in the Bull. of Minn. Sci., Vol. III, No. 3, p. 318. He says:—

"The collection embraces casts of Gasteropods and Lamellibranchs belonging to the genera Maclurea, Murchisonia, Cypricardites and Modiolopsis. The fauna of the St. Peter, as indicated by Sardeson's collection, is closely related to the Trenton, if not identical with it, and lends support of the views of those geologists who would correlate the St. Peter of the Upper Mississippi with the Chazy of New York."

In Wisconsin but few fossils have been found in either formation. I have never seen any except a fragment or so in the Lower Magnesian limestone.

From the stratigraphic relations, it has seemed to me that the Lower Magnesian limestone was more closely connected with the Potsdam than with the overlying formations. There is no real break between the formations, the Potsdam sandstone grading into the bottom of the limestone above. Between the limestone and the St. Peters there is, however, evidence of an erosion interval in the well marked unconformity in the region where I have worked in the S. E. Dr. Chamberlain and his associates of the earlier survey noted the unevenness of the Lower Magnesian surface, but, in part, at least, this unevenness was referred to an intraformational break, i. e., they supposed that condition occurred by which the newly deposited beds of limestone were somewhat broken up and heaped up into mounds by the waves, and over these more continuous beds were deposited, covering the ridges and hollows. On the uneven surface thus produced, the St. Peter sandstone was deposited with consequent varying thickness.

It appears to me, however, that this unevenness of the surface of the Lower Magnesian limestone is, in large part, at least in the area where I have been working, due to the erosion of the rock beds during an interval

of emergence as land. At Albany, southwest of Madison, a street cut shows eight feet or more of loose fragmental chert overlying a weathered surface of the Lower Magnesian limestone, and upon this loose material are the basal beds of the St. Peter sandstone. There is a little conglomerate here composed of sandstone enclosing somewhat worn fragments of the chert. I have found this bed of chert developed at intervals over quite a widespread area, as shown by exposures and well records. This seems to me clearly to indicate an erosion interval. The emergence of the Wisconsin land at this time does not, however, seem to have extended so far as northeastern Iowa, for there deposition seems to have been continuous. It is noted, however, as indicated above, that in northeastern Iowa there was sufficient shallowing of the water to cause the deposition of considerable sand in the upper part of the Oneota (Lower Magnesian group), such as would be expected if the land in Wisconsin emerged.

At the top of the St. Peter sandstone, again there are transition beds indicating a gradual change to the limestone-depositing conditions of the Trenton. This gradation usually takes place within a thickness of 10 feet or less.

There is no indication of a later interval of erosion during which the St. Peter sandstone could have been eroded so that we must conclude that its absence at certain places, as shown by exposures and well records, is due to the fact that its deposition did not overtop all the Lower Magnesian hills. The drill may thus pass from the Trenton right down into the Lower Magnesian limestone with no intervening sandstone, as Dr. Chamberlin explained for the well at Oshkosh.

On the other hand, there are places where the pre-St. Peters erosion entirely cut away the Lower Magnesian limestone and the St. Peter sandstone was there laid down upon the Potsdam sandstone with no intervening limestone. Mr. F. M. Gray, a driller of Milwaukee of wide experience, informs me that this was the case in many of the wells at that place, and at Wauwatosa. The log of the well at Lake Park, Milwaukee, as I interpret the data furnished by Mr. Gray, is as follows:

Lake Park Well, Milwaukee.

Hamilton group—		
Soapstone	80	feet
Cement rock	12	"
Soapstone	30	"
Waterlime? Brown limestone	30	"
Niagara limestone	320	"
Cincinnati shale	180	"
Galena and Trenton limestone	330	"
St. Peters sandstone	958	"
Potsdam sandstone		

The well at the E. P. Allis works in Milwaukee showed a like condition as far as the absence of the Lower Magnesian is concerned, but a bed of "red marl" occurs lower down, probably at the Mendota horizon. This latter condition occurs in other wells in the city. The Lower Magnesian is also absent at Wauwatosa.

The Lower Magnesian limestone is absent here and not included in the

330 feet referred to the Galena and Trenton, with the St. Peter absent, is shown by the fact that on going still farther west to Elm Grove and Waukesha, the Trenton (including the Galena) shows thickness of 320 and 300 at the two places, with both the St. Peter and Lower Magnesian present below.

This will explain things at the Sheboygan well referred to by Mr. Lane. (See Plate XIII, Vol. II, Geol. Wis., p. 335.) The thickness of limestone referred to the Trenton and Galena is less at Sheboygan than at the old city well at Milwaukee, and this latter thickness is less than that shown by the Lake Park well just referred to. In neither this old Milwaukee well or the Sheboygan well is the thickness of the sandstone penetrated below great enough to indicate surely that the Lower Magnesian limestone may not be present below, though it may be absent. Where the Lower Magnesian is absent, there is no means of drawing a line in the log of a well between the base of the St. Peter and the top of the Potsdam. It is reported to me that the well at Union Grove in Racine county penetrated more than 1,400 feet of sandstone below the base of the Trenton with no limestone beds at all. I do not know whether later and deeper wells at Sheboygan found any Lower Magnesian present at a greater depth than in this old well cited by Chamberlin or not.

It may really be, in the Oshkosh well, that it is the Lower Magnesian that is absent, with nothing to cut off the St. Peters sandstone from the Potsdam below, instead of the sandstone being absent and the Lower Magnesian and Trenton both being included in the 208 and 240 feet of limestone, as interpreted by Dr. Chamberlin. The local conditions, however, may warrant his interpretation.

As a general thing, however, in southeastern Wisconsin, the St. Peter sandstone is present, though varying greatly in thickness, so that the Trenton and Lower Magnesian is usually distinguishable.

The following is my interpretation of the well records sent by Mr. Lane, on the basis of the formations in eastern Wisconsin. There may, of course, be local conditions which, if known, might change this somewhat.

LOG OF WATER WORKS WELL AT MARINETTE.

Interpretation of Wm. C. Alden, Asst. Geol. U. S. G. S.

Pleistocene.

		Thickness.
1-70 feet.	Red sand and gravel	
70-85	? ?	85 feet

Galena limestone.

85-144 feet.	Round chipped limestone.....	59 feet

Trenton limestone.

144-196 feet.	Blue shales.	
196-240	Chipping limestone coarse.	
240-250	Chipping limestone.	
250-320	"Slate" light blue and white.....	176 feet

(Base of Trenton uncertain.) (St. Peter sandstone absent.)

Lower Magnesian limestone.

320-450 feet.	Chipping limestone coarse.	
450-550	Coarse chipping limestone light colored, and dolomite.	230 feet

Potsdam group.

550-560 feet.	White sandstone, very white, mealy-looking.
560-560	?White sandstone.
560-670	White and greenish, calcareous sandstone.
670-685	White sand.
685-712	Rounded white sand.

Huronian or Archean.

712-716 feet.	"Granite" (broken and lost).
716	Dark red quartzite.

LOG OF ST. P. & STE. MARIE WELL, GLADSTONE.

Location ?
Interpreted by Wm. C. Alden, Asst. Geol. U. S. G. S.

0- 87 feet.	Pleistocene	87 feet
87-326	Galena and Trenton limestone	234
325-404	St. Peters (probably), lime and sandstone in mixed layers	89
404-642	Lower Magnesian limestone	228
642-743	Potsdam, shell sandstone	101
743-	Hard rock, possibly Archean	...
	Total depth	743 feet.

Altitude about 605 feet.

NOTE.—Comparing this with the log of the well at Marinette, the elevation of whose curb is, I suppose, somewhere about 600 ft., it is seen that the two wells are very much alike except for the St. Peters, which is absent in one and 89 ft. thick in the other. The elevation of the base of the Trenton not far from 280 ft. in each and the thickness of the Lower Magnesian is about the same in each. If these beds are really St. Peters their absence at Marinette may be due to the higher elevation of the Lower Magnesian surface at that place, which the St. Peter deposition did not overtop. It is not possible for me to say, however, that this mixed sandstone and limestone is not a part of the Lower Magnesian group as in northeastern Iowa.

LOG OF THE WAGNER WELL.

The data below the Utica shale cannot be very satisfactorily correlated with the typical Wisconsin formations because of the discordance in the character of the beds. The following grouping is suggested, but the dividing lines might be moved up or down in each case:

Pleistocene.

0- 9 feet.	Gravel and clay	9 feet

Hudson River (Lorraine).

9- 54 feet.	Blue shale	45	feet
54- 67	Fossiliferous shale	13	
76- 95	Brown shale	28	
95-115	Blue shale	20	
115-123	Brown shale	8	
123-193	Gray shale	70	
193-201	Light gray shale	8	
	Total	242	feet
	Utica shale	251	feet
201-251 feet.	Bituminous shale	50	

Galena Limestone.

251-334 feet.	Limestone	83	feet
334-389	Fossiliferous limestone	55	
389-397	White limestone	8	
397-406	Dark limestone	9	
407-412	Quartzite (?)	6	
412-456	Limestone	44	
456-457	Quartz	1	
457-481	Limestone	24	
	Total Galena (possibly some Trenton)	230	feet

Trenton shale and limestone.

481-485 feet.	Blue shale	4	feet
485-499	Black limestone	14	
499-518	Limestone	19	
518-522	Blue shale	14	
	Total	51	feet

St. Peters group, possibly including some of Trenton and Lower Magnesian groups.

522-560 feet.	Sandstone, soapstone, limestone	38	feet
560-561	Red clay shale	1	
561-562	Sandy shale	1	
562-628	Limestone, soapstone, sandstone	66	
	Total	106	feet
628-640 feet.	Lower Magnesian, very crystalline limestone	12	feet
	Total depth	640	

I have gone into this considerably at length, possibly more so than is necessary. I shall be glad, however, if this is any assistance in understanding the relations of these formations.

You might send this letter to Mr. Lane, with any suggestions you wish to add. I shall be glad to be of any further assistance to him or to hear from him directly. I should like, myself, to have a better understanding of the real relations of these formations.

Respectfully,
(Signed) WM. G. ALDEN,
Asst. Geol. U. S. G. S.

We have at this point introduced a compilation of the Eastern Wisconsin section, from Chamberlin's report in the second volume of the Wisconsin Geological Survey reports. We find, coming up the Lake Michigan shore, a series of wells,—at Kenosha 1805 feet deep, at Racine 1600 feet deep, at Milwaukee 1700 or more, at Sheboygan 1475 feet deep, and at Manitowoc 1263 feet deep, all flowing and all ending in a sandstone of which the question arises whether it is the St. Peters, the Potsdam, or both combined. In this matter the letter of W. C. Alden is of interest, which is given above. But the practically important matter is, without question,—that along the Lake Michigan shore at from 1500-2000 feet plenty of water can be obtained in the sandstone, and that this water is distinctly mineral, but not very hard. Flows are likely to occur up to about 100 feet above the lake.

Back of the other side of the ridge made by the Niagara is another belt of flowing wells illustrated by Oshkosh, where there is standstone from 714 or 680 to 961; Appleton, where wells are 600 to 790 feet deep, and Marinette, where, as we have just seen, the sandstone still comes in at from 600 to 700 feet depth, and the depth of the Archean is still from 700 to 900 feet, which is continued up into Michigan.

Both these belts undoubtedly may be extended into Michigan, though I do not know as yet of any wells on this outer lake shore belt. The Manistique flows are not so deep.

Continuing the Oshkosh-Appleton-Marinette-Menominee line of wells we find others of various depths along the lake shore, as at Ford River, Escanaba, Gladstone, and Rapid River. All these wells start in the Trenton. The only one that begins above it is opposite Escanaba at the place of H. Wagner, of which I insert a record below, which differs somewhat from that given in the 1901 report (p. 228):

H. Wagner, Delta County, S. W. ¼ of N. W. ¼ of Sec. 8, T. 39 N., R. 21 W.

Drift.

Gravel and clay	9	

Lorraine (Hudson R.)

Blue shale	45	54
Fossiliferous shale	13	67
Brown shale	28	95
Blue shale	20	115
Brown shale	8	123
Gray shale	70	193
Light gray shale	8	201

Utica.

Bituminous	50	251

Trenton.

Galena—		
Limestone	83	334
Fossiliferous limestone	55	389
White limestone	8	397
"Upper blue" of Wisconsin, Trenton?		
Dark limestone	9	406
"Upper buff"?		
Quartzite (? geodes)	6	412
Limestone	44	456
Quartz (? geodes)	1	457
Limestone	24	481
"Lower blue."		
Blue shale	4	485
Black limestone	14	499
Limestone	19	518
Blue shale	4	522
"Lower buff."		
Sandstone, soapstone and limestone (perhaps in part St. Peters)	38	560

St. Peters.

Red clay shale (weathered surface of Lower Magnesian?)	1	561
Sandy shale	1	562

Calciferous.

Limestone, soapstone and sandstone	66	628
Crystalline limestone	12	640
Depth of hole		640

As complete samples have not been seen it is not certain that the record is correct, but the probabilities are that the lower part of the well extends into the Calciferous or beds below the Trenton. I was, however, informed that upon re-measurement, the well proved not as deep as was supposed. In a recent well near by at 860 to 900 feet a broken formation, either the conglomerate of the Archean quartzite, was apparently struck, with a good body of sandrock above. We can see in the beds from 481 feet to 562 feet down about where the shale comes in, which appears in the records at Menominee and other points. Around Maple Ridge there was a well which went through 30 feet of limestone and then, as reported, 150 feet of soft blue shale, which may correspond to and represent some of the blue beds of the Trenton. At Flat Rock, near Escanaba, a flowing well is said to be 800 to 900 feet deep. But not all flowing wells need to be this deep. At the charcoal furnace north of and near Gladstone, there are a group of flowing wells that belong to the Cleveland Cliffs Co., described below.

At Rapid River, Section 19, T. 41 N., R. 21 W., or nearby, there are eight or nine flowing wells which are supposed to go through 270 feet of the Trenton rock and strike sandstone below. One is 270 feet deep, rises three or four feet above ground and the temperature of the flow is constantly 45.8° F. by measurements July 12, 1902, and Aug. 26, 1903. Another opposite Dillabaugh's is 275 feet deep and has a 10-foot head. Seven miles north and two miles east of Rapid River there was a well put down for oil on Sec. 34, T. 42 N., R. 21 W. A set of samples were to have been kept for me, but were said by Mr. M. D. Kelley to have been stolen from him. As near as I can judge, there was about 300 feet of more or less oily Trenton and below that, down to within 20 or 30 feet of the bottom, was very largely white sandstone. The extreme bottom was apparently decomposed schist of the iron bearing series. At 170 feet or more above was sandstone, some of it a very clear white sand. The flow outside the casing, which is 800 feet deep, was very strong; the temperature being 47.3° F., and the amount over a quart a second. It probably works around the casing from about the same level as the Rapid River wells or somewhat deeper. Assuming, however, that certain samples which I found left in the boxes were arranged inversely from the bottom up each 10 feet, which seemed to be the system they were working on, we have the following record which harmonizes with what might be expected. The papers have recently[1] had many accounts of flows of oil from this well, or one near it, but while there is little doubt but what there is a strong flow and some oil the relative proportions of oil and water are quite possibly reversed.

RAPID RIVER OIL WELL, HYPOTHETICAL RECORD.

200 paces W., 505 S. of N. E. corner Sec. 34, T. 42 N., R. 21 W.

Surface.

Swamp peat and muck	3 to 6	6
Marl	10	16
16 feet 10 inches casing.		

Trenton.

Dolomite with geodes lined with fine dog-tooth spar calcite and filled with oil "gum"	264	?280

St. Peters horizon?

Signs of oil. Strong flow of water, over 1 quart a second. Temperature 47°3 F.		
An old well 300 feet west was 202 feet deep	350	630

Calciferous?

S. at 620 box 380 a dolomite.

[1] Saginaw Evening News, 10/25/1903; Marquette Mining Journal, 12/2/1903; Gladstone Delta, 12/5/1903, and 10/31/1903; Detroit Tribune, 11/13/1903; Iron Mountain Press, 11/5/1903; Crystal Falls Drill, 11/28/1903; Chicago Record-Herald, 11/1/1903.

Potsdam.

"White sandstone comes in 600-700 feet down." Clear white glass sand (Upper Potsdam of Rominger).		
Samples, boxes 300 to 370	80	710
Reddish sandstone coarse.		
Sample, box 290	10	720
Coarse red sandstone.		
Sample, boxes 250 to 280	40	760
Feldspathic sandstone.		
Box 290	10	770
Coarse mixed very micaceous red sandstone.		
Box 210-230	30	800

Last samples, large fragments of decomposed chloritic schist, like Archean rocks.

This should be compared with a record of a well put down for water at the station of the Minneapolis, St. Paul & Sault Ste. Marie R. R. at Gladstone, elevation 605 A. T., which according to letters of Mr. P. Swenson of the company, and J. F. McCarthy, the contractor, must be about as follows:—

Pleistocene.

	Thickness.	Total.	Dates and Remarks.
Old dug well (in sand)	13	13	Began May 9.
Quicksand	38	51	
Till (clay and hard pan)	10½	61½	
Sand and gravel	15	76½	
Clay and limestone	10½	87	
Boulders	4	91	

Trenton.

Limestone	234	325	
Lime and sandstone in mixed layers	89	404	

St. Peter's horizon? Some water at 400 feet.

Calciferous.

Limestone	228	642	At 580 Sept. 15. Compare Rapid River 630.

Sample 632 is crystalline magnesian limestone.

Potsdam.

Shell sandstone.

Sample at 742 feet, white, round sand, like Rapid River, 630 to 710. At 690 feet Oct. 1. Main water flow, 150 gallons a minute. Hardness only 5.°86. Finished Oct. 9.

Hard rock, not Archean granite at the end.

Average progress 5 feet a day, but from Sept. 15 to Oct. 1, and Oct 1 to Oct. 9, 7 feet a day.

It is a pity that we cannot have analyses of each water separately, yet the low hardness is significant. Though drawing from a deeper source, it is less hard than the Marinette, and one of the Menominee wells, and the Escanaba waters, including one of the shallower artesian wells given below.

ESCANABA WATERS.

ANALYZED BY VICTOR C. VAUGHAN.

Number	243.[1]	244.[2]	296.[1]
Date	12 8 94	12 8 94	11 30 95
Reaction	alkaline	alkaline	alkaline
Hardness	8°	8°	11°
Total residue	240	140	290
Inorganic residue	180	80	270
Organic residue	60	60	20
Cl as NaCl	11.55	11.55	3.30
Sulphates	trace	trace	trace
Free ammonia	0.069	0.075	0.028
Albumenoid ammonia	0.33	0.29	0.165
Nitrates	trace	trace	.....
Nitrites	trace	trace	.....
Bacteria in 72 hours	250	liquefaction.	120

[1]Artesian well. microscope shows small deposits.
[2]Slightly milky, stale odor, no reaction; unicellular plants and animal water fleas, vegetable debris and organic matter.
[3]Dirty yellow color, stale odor, no reaction; Algae, desmids, unicellular, plants and animals, vegetable debris inorganic matter. This and No. 244 are probably from the bay.

An important practical deduction, therefore, is that by going to the deeper waters in the Potsdam and casing off the waters from the limestone a softer water can be obtained. In explanation of this it must be remembered that there is an upward pressure and circulation which will prevent the limestone waters from working down into the sandstone to any great degree, while the Potsdam and Archean normally contain soft waters. The wells at the furnace, two miles north of Gladstone, deserve a moment's attention here, for there appears to be an exception, but it is not. There are at least five flowing wells here.

1. The one on the mainland, at the south end of the row of tenements flows a quart or more a second with a temperature of 45.5° to 46°. It is housed; there are two casings, the 8-in. comes one foot above ground, and the 4-in. two feet more, and there is a curved neck of inch pipe 2½ feet long.

2. At the north end of the tenements has a similar but fluctuating flow as though affected by the pumping of the wells at the plant. Temperature, 44.9°.

3. Is the most southwestern of the plant wells, put down in the winter of 1900-1901, said to be 174 feet deep in sand and gravel. Temperature, 47.7° to 47.8°.

4. The northern of the three wells at the plant was put down deeper, i. e., to 500 feet for more water, and did not get it, but got more lime. Temperature, 49° to 49.3° F. This, however, evidently did not go deep enough. It should be put down 200 feet more.

5. Inaccessible; capped.

Before passing to the waters of the Archean area, we will include a few more notes on those of the sedimentary or eastern end of the Upper Peninsula. Over at Brampton, west of Rapid River, the wells go through 20 feet of hard pan and then find water in the limestone. A little north of the station on section 21, T. 41 N., R. 22 W., is a spring with a strong flow of over a quart a second and a temperature, July 12, 1902, of 48° F. Three miles north, at Perkins, there are wells from 150 to 250 feet deep through rock all the way, and wells of the same general type occur at Maple Ridge and Lathrop. Similar wells have been put down near the Wisconsin line at Ingalls by James Lucas.

At Talbot there is a drilled well close to the station. At Daggett there is a well, put down by W. H. Dolan, which at 40 feet was in a hard, white non-effervescent clay shale that might be valuable. At 45 feet it passed into a dolomitic sandstone. At 60 feet the sandstone was still calcareous, but at 80 feet it was almost pure quartz sand. This well must be in the Calciferous, possibly finishing in the Potsdam.

A short record of a well at Neebish Island down into the Potsdam sandstone, is given in the annual report for 1901. Mr. Alden suggests as a possible correlation for it:—

"?No samples	111	
Trenton limestone	112	223
St. Peter's sandstone	161	384
Potsdam	33	417
?Pre-Cambrian shale and quartzite	110	527"

I think that the bottom is conglomeritic Potsdam, and the limestone in part, at least, Trenton, yet I am not sure but that the Lower Magnesian is wholly gone and the white, sugary sandstone is St. Peter's. At any rate the top of the true Potsdam seems to be similar at times.

The drillers' full record is as follows:—

Drillers' "Log." [1]Neebish Well.

	Thickness.	Total.
Clay, boulders, and sand	33	33
Limestone, hard	1	34
Limestone, vein water, soft	1	35
Limestone, hard	14	49
Limestone, gritty, softer	40	89
Limestone, darker in color, not so gritty but harder [111-138 light colored]	17	106
Limestone, softer	13	119
Limestone, shale	2	121
Limestone, hard	3	124

[1]Matter in brackets are notes on samples, the rate of effervescence with acid varies, being greatest at 123 and 190 to 200 feet, least at 138 and 211-223 feet.

	Thickness.	Total.
Limestone, softer	3	127
Limestone, hard	7	134
Limestone, softer	6	140
Limestone, shale	2	142
Limestone	7	149
Limestone, hard [148-158 light colored]	4	153
Limestone, softer	5	158
Limestone, shale [bluish, thin chips]	5	163
Limestone, brittle [bluish, chipping, 163-200]	22	185
Clay	1	186
Limestone, brittle	4	190
Shale; cased here for first time	8	198
Limestone	2	200
Shale, [large chips, thin bedded]	5	205
Limestone, darker in color [sandy dolomite]	9	214
Limestone, shelly, full of little seams	9	223
White sand rock	10	233
Shale	2	235
White sand rock,[1] got first flow water at 250 feet, and more in several places in going through the sand	176	411
Sand; harder, looks like granite boulders pounded up	8	419
Sandy shale;[2] sand pumpings look red but when washed out are black	87	506
Sand rock	21	527

Average, about 10 feet per day drilling. Worked just day time.

Reported by A. W. Palmer, Jan. 16, 1900.

Location, across the west channel on the mainland opposite Trombleys and about 1,000 feet south of north line of Trombleys; about 100 feet from water in the Sault Ste. Marie river and 6 or 7 feet above level of river about 1½ miles below the rapids in the river.

The St. Ignace flowing wells have been reported in the annual report for 1901. The temperature is about 51°.

At Manistique flowing wells are from 200 to 800 feet deep. At 800 feet in the Hiawatha House well a flow was struck, which lifted the drill and had 30 to 40 feet of head, occurring in a "not hard shell rock" (Trenton?). John Luce is in charge of 30 wells which furnish city water and are also used for fire protection. They are cased from 30 to 40 feet down and range in depth from 250 to 500 feet; the latter going through the seam of water and not gaining in depth. This was put down for salt, but the tools were lost in the bottom of the hole. Near the level of the main streets the water comes within a foot of the ground, others have head up to 16 feet. The character of the water is hard, for it is in limestone. The surface rocks of the quarries are limestones of the Niagara.

---

[1]Clean white glass sand rock ... 84-411.

[2]Coarse red conglomerate, grows coarser, 417-506; at 490 red ... le of Huronian quartzite; 506-51 510-527, material mainly Huronian.

At the Burrell Chemical Co. is a well 300 feet deep all the way through limestone; temperature of flow, 46° F. They used to pump this heavily, but at the time of my visit they were stopped by fire and all other flows had increased very much. This well is out at the end of Cedar street. Across the river is another well with a strong flow. One of the city wells at the corner of Geer street and Houghton avenue, 280 feet, has a temperature of 45° F. (July 14, 1902) to 45.5° (Aug. 26, 1903) and a strong flow.

During the summer of 1903 a number of new city wells were put down by Kenney and Coleman, as follows:—

1. Corner Garden avenue and Potter street, 6-in. pipe and a two foot pipe horizontal; just finished Aug. 26. There is a good flow of clear hard water at a temperature of 45° F., not more than 15 feet above lake, 226 feet deep, a very little water was struck at 140 feet but no head. Mr. Coleman gives the following notes of the hardness:—

0 to 80 feet, hard drilling.

80 to 140 feet, soft drilling.

140 to near end, hard drilling.

Then softer, but just over the water hard drilling, as almost always the case.

The record is as follows:—

Sand	2	2
Dolomite, light buff, massive	2	4
Light dolomitic limestone	9	13
Bluish white dolomite (harsh feel)	11	24

Above beds probably belong to Rominger's[1] third or uppermost member of the Niagara, and to the Racine or upper Coralline of Wisconsin, corresponding to the surface section and that in the quarry as follows:

Cherty dolomite bluffs (Pentamerus)	10	10
Solid dolomite	5' 4"	15' 4"
Bluish dolomite	10	25 4

Blue clayey seam of partition which at points is full of small *Pentamerus oblongus* not over one inch in diameter.

Brownish crystalline granular beds with Favosites and other corals	3	28 4
With open druses, lined with calcite	3	31 4
Fine grained bluish dolomites with Syringopora	5	36 4
Open grained brown dolomite with purple cavities	4	40 4
Open grained brown dolomite	4	44 4
Brownish crystalline dolomitic limestone.	16	40

Compare quarry beds from 25 feet to 44 feet.

Light bluish dolomitic limestone	12	52
Buff crystalline cherty limestone	13	63
White limestone	7	70
Buff crystalline dolomitic limestone	10	80
White limestone	27	107
Mottled gray dolomite	18	125
Buff dolomite	11	136
Yellow dolomite	22	158
Gets harder and a little water, no flow at 140 feet.		
Yellowish limestone	30	188
Yellowish dolomite	12	215
This may be base of coralline, top of Byron beds of Wisconsin, Rominger's lower division.[2]		
White thin banded lithographic dolomite..	10	225

[1] Vol. I, Part 3, p. 37.
[2] Volume I, Part 3, p. 37.

Compare outcrops on sections 24 and 25 to the north.

At bottom white limestone.....	15	240

2. Mackinaw avenue and Elk.
3. Cedar street, near L. Rice.
4. Garden avenue and Potter.

In this rock with a 30-foot string of 4-in. tools they made 15 to 20 feet a day.

The same contractors put down a well 240 feet deep at the Burrell Chemical Works, while across the river, i. e., on the northwest side of the town, are a couple of wells put down 208 and 210 feet.

North of Manistique, on the Manistique and Northern R. R., on sections 24 and 25, T. 41 N., R. 16 W., very white, hard limestone is exposed showing by bandings that weather out, that it was a limestone mud.

Apparently the well begins in the uppermost of Rominger's three fold division of the Niagara, and goes through the middle or coral beds of the Wisconsin Survey, and it is worth noting, showing some beds of real limestone, low in magnesia. The bottom appears to be in Rominger's lowest division, or the Byron beds of the Wisconsin geologists. If we suppose the top to be at 426 of the St. Ignace well No. 2, the bottom layers with water might compare to the water found there at 680 feet. The bottom beds may correspond with those found on sections 24 and 25 of the township immediately north.

It seems to me it would be desirable to put one well down into the Potsdam, that is over 1,400 feet deep—and see what kind of water could be obtained there. I don't consider the bare possibilities of oil in the recommendation, but the water might be softer than in the present, and if not it would be pretty sure to be a valuable and probably palatable mineral water. One would expect it to be of the same class as the deepest wells of Chicago, Milwaukee, Manitowoc and Sheboygan.

All of the present wells, except perhaps the Hiawatha House 800 feet well, which may be from the Trenton, are in the Niagara and the strata may be compared with samples which have been saved from St. Ignace. Probably the sandstone struck at 897 feet, the bottom of the first well there (pl. 63 of Vol. V), may be the horizon of many of these wells. The record of the second well is given on page 228 of the 1901 report and we notice that there are strong flows of water encountered in the Niagara from 575 feet, that is, 65 feet, below its top, down. On page 227 of that report is given the record of a flowing well on Neebish Island, Mr. Alden's correlation of which is given above; the sandstone near the bottom being like those near the bottom of the Rapid River well.

As I have said, flows and springs are found or may be expected for a good ways back from the Lake Michigan shore, as at Newberry. The surface deposits of the drift are commonly not very thick over the Niagara. Over the Lorraine and Utica shales they seem to be thicker. There are extensive swamps; there is a good deal of surface sand, and it is not difficult to get surface wells. Over on the north side of this region at Grand Marais, T. 49 N., R. 14 W., a well was put down in 1899-1900, 1,200 feet deep. It tapered from 8-in. to 6-in. in diameter and was cased for the first 100 feet. It is about 100 rods from Lake Superior and about 30 feet above the lake level. It was started on the strength of artesian wells at Newberry,

—citizens thinking that the same flow might be struck there and not appreciating that they were on the other side of the divide. It seems to have found some 1,100 feet of Potsdam, under 100 feet of drift. The well was 8 to 6 inches in diameter, cost $3,500, and the water did not flow. There was 100 feet of casing, but it has now been abandoned, and though the water was reported as extremely hard we cannot now tell its nature. Mr. Arthur D. Wood writes:—

"The Grand Marais well is located about 100 rods from Lake Superior, about 30 feet above the lake level. It was started on the strength of the Newberry artesian wells, the citizens of this city thinking that the same flow might be struck from here.

"The drill went through sand for the first 100 feet and then came in contact with hard pan of a sandstone nature of different colors. In some places this was harder than in others. During the drilling of the 1,200 feet several hardheads were met with, otherwise it was principally sandstone. The water in the well never flowed, but at times would rise to within a few feet of the surface and then it would not be seen again for a week at a time.

"The well is a thorough test that 1,200 feet will not strike a flow in the section.

"(Signed) ARTHUR D. WOOD.

"Grand Marais, Mich., 7/30, 1900."

The only reliable analysis of a well in the Potsdam sandstone is of the one put down by the Calumet & Hecla Company, near the Calumet & Hecla stamp mills at Lake Linden. They have drilled wells 1,500 feet deep, all the way through a monotonous series of sandstone strata. One has been analyzed. The same company have at their smelting works (section 7, T. 55 N., R. 32 W.) another well which goes down 500 feet, beginning 8 feet above the level of (Torch lake) Lake Superior. Water is usually quite clear, but occasionally brings up some red sand. There was much surface water cut off by a 10-in. casing for 30 feet. There was 90 feet of 8-in. casing down into the solid rock; 104 feet of solid sandstone followed. There is 200 feet of 4-in. pipe inside the 8-in. casing and 50 feet of 3-in. pipe below that; 200 feet of the well now having filled up with sand. When not pumping, the water stands at 25 to 30 feet below the surface, but can be pulled down with a pump to about 150 to 180 feet. It was drilled in 1887. The analysis by Mr. G. L. Heath, is as follows:—

C. & H. Stamp Mill Well.

	Grams per ton.
Silica	10.87
Carbonate of iron ($Fe CO_3$)	5.90
Sulphate of lime ($Ca SO_4$)	10.90
Carbonate of calcium ($Ca CO_3$)	43.59
Carbonate of Magnesium ($Mg CO_3$)	27.92
(Salt) Chloride of sodium ($Na Cl$)	52.69
Traces of chloride of potassium and nitrate of sodium.	
	151.87
Loss on ignition, organic matter and carbonic acid of bi-carbonates	32.33
Total solids	184.20
Parts in 1,000,000, by weight, taking Sp. Gr. of this water as unity.	

Compare the analyses on pages 163 and 164.

It is interesting to contrast this with the well at Freda, on the other side of the copper range, not so deep and also all the way through red sandstone, of which we will speak a moment later. In discussing the water of the copper country, we may give a group of analyses, showing the character of the surface waters and shallow mine waters. Most of these were made by Prof. Geo. A. Koenig or under his direction, and I owe them to him or the mine officers for whom they were made. The collection will be found valuable, I think, as showing what kind of boiler waters may be expected from various classes of water.

Water from Old Estivant Property, Copper Harbor.[1]

	Grams per ton metric.
Calcium carbonate	206.0
Magnesium carbonate	107.2
Magnesium chloride	36.
Sodium chloride	26.4
Sodium sulphate	52.4
Sodium carbonate	41.6
Silica	83.2
Organic matter (humus)	166.0
Total	718.8

[1] Sent by Osgood to test for boiler use, figures raised from 250 cc.; strongly carbonated and low in chlorides, upper type. L.

Well at Arcadian Mine location, Aug. 23, 1898.

		Grams per ton metric.
Sodium chloride		2.15
Sodium sulphate		9.76
Sodium silicate		15.00
Calcium carbonate		41.90
Ferrous carbonate		1.40
Magnesium carbonate		2.40
Na_2O	6.99	
K_2O	1.70	
	8.69	
$C_{60}\ H_{54}\ O_{27}$		20.90
		93.51

This has about the same hardness as the Boston Pond, not far off, upper type.

The following are some figures of analysis of the water at the Tamarack dock.[1]

Tamarack Dock.

Total solids	177.2
Organic loss by ignition	22.8
Inorganic solids	154.4
Sodium chloride (from silver chloride precipitated)	9.6
Sodic sulphate	24.0
Iron and aluminium oxide	1.0
Silica[2]	16.7
Balance probably mainly calcium and magnesium carbonates	103.1

What the undetermined balance consists of is shown by the next analysis.

Filtered Portage Lake Water.[3]

	Grams per ton.
Calcium carbonate	63.7
Calcium chloride	30.7
Magnesium chloride	2.35
Magnesium sulphate	6.45
Sodium chloride	14.45
Sodium silicate	7.9
$H_2\ Si\ O_4$	15.7
	139.75
Albumenoid ammonia	.06

[1] Computed from figures per fourth litre.
[2] Silica, iron and alumina in two litres .0354 gr.
[3] Feb. 17, gave 279.5 mg. in 3 litres and by analysis.

Portage lake should, of course, be intermediate between Lake Superior and various other waters, except so far as it might be affected by the mine drainage of the Isle Royale, Quincy, and other mines and the towns and metallurgical operations. These introduce the earthy chlorides.

Here is an analysis of the water of Thunder River, near the Wolverine mill, which, however, does not affect it:—

Thunder River.

	Grams per metric ton.
Calcium carbonate	27.3
Magnesium carbonate	8.51
Ferrous carbonate	2.03
Sodium chloride	1.70
Sodium sulphate	2.84
Sodium silicate	14.48
	72.49

This has about the same amount of mineral matter as the Houghton water supply or the tank that used to supply the College of Mines, gathered from shallow springs, from the top of the hill back of the school.

College of Mines.[1]

	Per million.
Alumina	1.82
Calcium carbonate	16.25
Ferrous carbonate	.49
Magnesium carbonate	15.82
Magnesium sulphate	4.69
Silica	8.20
Sodium silicate $(Na_2 K_2 (Si O_3)_2)$.	3.90
Sodium chloride	trace
Free ammonia	.03
Albumenoid ammonia	.15
Humus (organic)	27.06
	78.40

The small artificial pond for the boilers of the Franklin Junior Mine,—Boston Pond, is about equally soft.

[1]Tank. Shallow springs from the top of the hill back of the school, analyzed by A. Formis.

Franklin Junior.[1]

Calcium carbonate		29.00
Ferrous carbonate		1.16
Magnesium carbonate		9.50
Sodium silicate		1.16
Sodium sulphate		2.75
Sodium chloride		2.21
Na_2O	1.32	
K_2O	0.60	
Humus (organic)		37.60
		83.38

Some analyses of water near the Winona mine are:—

Winona.

(1) Yellow, with an unpleasant smell and color.

	Grams per metric ton.
Calcium carbonate	66.60
Magnesium carbonate	24.15
Calcium sulphate	14.55
Silica	3.25
Sodium chloride	31.50
Potassium chloride	7.50
Humus (organic matter)	25.05
Free ammonia	1.00
Albumenoid ammonia	3.40
Total directly	177.00

(2) Turbid with salt, but no smell nor color; pleasant taste.

	Grams per metric ton.
Calcium carbonate	131.25
Magnesium carbonate	26.45
Ferrous carbonate	20.40
Sodium chloride	9.65
Free ammonia	.05
Albumenoid ammonia	.29
	188.09

[1]Small artificial pond.

(3) A spring gives the following analysis in grams per metric ton:—

Calcium carbonate	45.06
Magnesium carbonate	11.76
Ferrous carbonate	0.153
Sodium chloride	3.41
Sodium sulphate	.28
Sodium aluminate, $Na_6 Al_2 O_4$	.322
Silicate, $Na H SiO_4$	20.980
Ammonium nitrate, $NH_4 NO_3$	.108
Albumenoid ammonia	2.22
Organic matter	5.02
Sum	89.313
Total directly determined	93.4

The analyses of the pond at the Tamarack, and that by G. L. Heath on page 166, show the kind of contamination produced by the deep waters of the copper mines, one with earthy chlorides.

So far as the hardness goes, the amount of calcium, magnesium, and ferrous carbonates, does not fall below that in Lake Superior, say about 50 grams per ton and is not often more than double that, i. e., there should be from 3° to 6° of hardness. With this, agrees analysis 156 of the Hancock water by V. C. Vaughan, while No. 326 is extra high.

HANCOCK.

ANALYSES BY V. C. VAUGHAN.

Number	156	326
Date	9 20 92	7 29 96
Color		
Odor	(1)	(2)
Reaction		
Hardness	4°	7°
Total residue	[1]12	170
Inorganic residue	[2]10.5	110
Organic residue	[1]1.5	60
Na Cl	2	4.95
Permanganate reduced	3	2
Free ammonia	.07	0.028
Albuminoid ammonia	.40	0.136
Nitrates	Distinct trace	trace
Nitrites	0.0	trace
Bacteria in 72 hours	575	Liquefied

[1]Slight offensive odor and markedly acid reaction; microscope shows indeterminate granules and a few fresh water algæ. Figures returned for inorganic residue, etc., are all ten times too small.
[2]Trace of sulphates and small deposit of vegetable debris.

We have had an analysis of Teal lake ice. It will be fit now to give analyses of this and other lakes of the iron bearing rocks. First near Ishpeming and Negaunee.

	Ishpeming lake.		Negaunee—Teal lake.
Number	153[1]	191	179[2]
Date	7 14/92	7 8 93	9/22 93
Hardness	2°	.....	.....
Total residue	42.85	33	.....
Inorganic residue	28.52	25	.....
Organic residue	14.33	8	.....
Na Cl	0.75	2	0.75
Permanganate	3.5	4	.....
Free ammonia	0.08	.03	0.6
Albuminoid ammonia	0.09	.10	.40
Nitrates	Distinct trace	traces	trace
Nitrites	0.0	traces	trace
Number of bacteria in 72 hours	575	300	2,600

[1]Microscope shows indeterminate granules and bacteria.
[2]Reaction of inoculation positive; vegetable debris.

Compare analyses and remarks on page 121.

These are very soft. At Iron Mountain, on the other hand, the waters are hard and the Randville dolomite occurs around there. There may be mine water contamination.

IRON MOUNTAIN ANALYSES OF PUBLIC WATER SUPPLY.

Location.	Outlet of lake Antoine.	Waterworks well.	City hydrant.	Lake.
Number	841	822	833	1204
Date	6/10/90	6/10/90	6/10/90	6 24/91
Color				slight sediment
Odor				
Reaction				
Hardness	13°	13.3°	12°	11°
Total residue	120	150	164	125
Inorganic residue	69	69	118	58
Organic residue	51	81	46	67
Cl as NaCl	4.125	4.95	4.95	6.93
Permanganate reduced	29.402	32.149	25, 34.9	28.331
Free ammonia	00.358	0.388	0.502	0.11
Albuminoid ammonia	0.342	0.444	0.57	0.322
Nitrates				
Nitrites		very faint trace	faint trace	
Bacteria in 72 hours	3	6	6	2

[1]Algæ diatoms, *Draparnaldia*, *Diatoma vulgare* Foraminifera.
[2]Colorless amorphous matter, Dark colored amorphous matter, algæ, crystals, *Crenothrix*, *Diatoma vulgare*, *Zoogloea*.
[3]Colorless amorphous matter, yellow amorphous matter, algæ, a few diatoms.
[4]Microscope 100 and 500 diam., Diatoms, colorless amorphous matter, monads.

IRON MOUNTAIN.—CONTINUED.

Location.	Lake.	Well.
Number	134[1]	135[1]
Date	1891	1891
Color		
Odor	faint	
Reaction		
Hardness	8.6°	1
Total residue	150	260
Inorganic residue	100	140
Organic residue	50	120
Cl as NaCl	1.3	1.0
Permanganate reduced	7.584	10.428
Free ammonia	.15	.08
Albuminoid ammonia	.34	.106
Nitrates		trace
Nitrites	trace	strong trace
No. of bacteria in 72 hours	4	2

[1]Trace of sulphates.

IRON MOUNTAIN.—CONTINUED.

Location.	Public water supply.	Water works.	Water works.	Public water supply.
Number	131[1]	128[2]	67	182[3]
Date	1/28/92	11/23/91	4/14/90	8/25/93
Color				
Odor				
Reaction				alkaline
Hardness	13.7°	13.2	8.5°	
Total residue	130	220	210	
Inorganic residue	88	150	130	
Organic residue	42	70	80	
Cl as Na Cl	0.42	2.	4.5	0.2
Permanganate reduced	7.9	0.15	7.8	
Free ammonia	0.7	0.005	0.26	.006
Albuminoid ammonia	0.05	0.025	0.27	.04
Nitrates				
Nitrites		trace	trace	
Bacteria in 72 hours	4	13	9	250

[1]Microscope shows indeterminate granules.
[2]Microscope shows fine grains of sand. Trace of sulphates.
[3]Microscope shows a few vegetable fibres.

IRON MOUNTAIN.—CONTINUED.

Location.	
Number	1891
Date	7/93
Color	.....
Odor	.....
Reaction	alkaline
Hardness	.....
Total residue	.....
Inorganic residue	.....
Organic residue	.....
Cl as Na Cl	0.2
Permanganate reduced	.....
Free ammonia	.005
Albuminoid ammonia	.05
Nitrates	.....
Nitrites	.....
Number of bacteria in 72 hours	3,500

[1]Microscope shows a few vegetable fibres.

IRON MOUNTAIN.—CONCLUDED.

Location.	Lake.	Water works.
Number	121[1]	122[2]
Date	6/24/91	7/2/91
Color	slight sediment	Contain much floc'lent matter
Odor		
Reaction		
Hardness	11.2°	11°
Total residue	143	120
Inorganic residue	67	72
Organic residue	76	48
Cl as NaCl	7.09	4.0
Permanganate reduced	35.522	20
Free ammonia	0.092	0.03
Albuminoid ammonia	0.314	0.15
Nitrates		
Nitrites		
Number of bacteria in 72 hours	2	4

[1]Microscope—Diatoms—Colorless amorphous matter. Monads.
[2]Microscopic appearance—Vegetable fibres and bits of decayed wood.

Norway is very similarly located to Iron Mountain and the analyses of wells and other sources are similar, but a shade less hard, from 10° to 12°.

NORWAY.

Number	124[1]	125[2]	126	183[3]	184[3]
Date	7/2/91	7/2/91	11/8/97	8/16/93	8/16/93
Color	.....	sediment	.....	.....	.....
Odor	.....	.....	.....	.....	.....
Reaction	.....	.....	.....	feebly alkaline	feebly alkaline
Hardness	10°	12°	10°	9°	11°
Total residue	120	126	101	280	340
Inorganic residue	111	111	95	220	270
Organic residue	9	15	6	60	70
Cl as Na Cl	1.0	3.0	0.5	1.6	1.4
Permanganate reduced	3.2	3.5	1.2	3	3
Free ammonia	0.01	0.02	0.005	0.005	0.005
Albuminoid ammonia	0.03	0.15	0.01	0.10	0.08
Nitrates	.....	.....	.....	0.05	0.06
Nitrites	.....	.....	.....	0.0	0
No. of bacteria in 72 hours	3	5	2	480	150

[1]Microscope—Deposits.
[2]Bits of vegetable fibres.
[3]Sulphates 2, microscope shows only indeterminate granules.

Number	185[1]	377[2]
Date	8/16/93	11/19/97
Color	.....	Milky
Odor	.....	Ammoniacal on warming
Reaction	feebly alkaline	alkaline
Hardness	11.5°	9.2
Total residue	240	430
Inorganic residue	160	255
Organic residue	80	175
Cl as NaCl	1.2	16.5
Permanganate reduced	3.5	2-
Free ammonia	0.02	1.4400
Albuminoid ammonia	0.30	trace
Nitrates	1.0	.....
Nitrites	0	.....
Number of bacteria in 72 hours	300	liquefaction

[1]Trace of sulphates. Microscope shows specks of vegetable matter.
[2]Some sulphates present—considerable amount of amorphous material, probably a salt of ammonia.

There was a flood of water in the Vulcan mine, near Norway, in the fall of 1903, which almost drowned them out (did drown two mules), and analyzed as follows, in grams per metric ton:—

Insoluble matter, clay and SiO_2	4.4
Solid solubles	340.00
Organic matter	52.3
Carbon dioxide	37.3
Non volatile solids	250.4
In solution.	
Silica	5.8
Alumina	4.4
Ferric oxide	trace
Calcium oxide	84.4
Magnesium oxide	62.8
Sulphur anhydride, SO_3	36
Chlorine	61
Potassium	trace
Sodium present not determined, very small.	
Strontia and lithia	0
Total by addition	254.4

We may consider this combined as follows:—

Ca SO_4	61.2
Ca CO_3	85
Ca Cl_2	26.6
Mg Cl_2	73.3
MgO, SiO_2	9.7
MgO, Al_2O_3	6.2
MgO representing bases combined with organic matter	30.6
	292.6

E. E. Ware, laboratory of E. D. Campbell, Ann Arbor.

Compare non-volatile solids and CO_2=250.4 plus 37.3=287.7. The hardness of 308 grams per metric ton would be equivalent to about 18°.

The water is not unlike Vaughan's waters 183 and 184 in hardness and inorganic residue, but has a comparatively large amount of chlorine, and yet a very small amount of sodium, which is very peculiar, but reminds one of the deeper waters of the copper country much diluted.

The temperature of the water at the 12th level, 1,000 feet from the surface, was: at the shaft, 57.°2 F.; at the first winze, about 100 feet west of the shaft, 60.°6; and the west end, almost 300 feet west of the shafts, 58.2°.

See annual for 1901, p. 246. According to the observations there, the mine water at 1.210 feet was 56°, and at 270 feet, 45.°8. This water is then, abnormally warm,—either from working up(?) or the heat from casing, friction, and decayed timber.

The question arose whether it had any immediate surface source, and accordingly, analyses were made of the surface waters.

1 is from Lake Hanbury, into which the mine water drains.

2 is from water in the gravels at Norway, from the Aragon mine sand shaft, used for city supply.

3 is from Pine creek.

Comparing them with the deep mine water, there is a large amount of carbonates, a variable amount of sulphates, and much less chlorine than in the mine water, which, therefore, is probably not derived from any of them.

Feb. 19, 1904.

	Lake Hanbury.		Sand shaft.		Pine creek.	
Total solids	301.4		762.5		205.2	
Inorganic solids	268.1		668.1		172.7	
Carbon di-oxide	82.8	1.88	100.5	2.28	56.2	1.28
Lime	63.9	1.14	195.2	3.48	57.6	1.022
Magnesia	52.5	1.325	88.0	2.2	33.4	.835
Chlorine	3.6	.1019	3.8	.1074	1.0	.028
Sulphuric anhydride	33.6	.42	245.8	3.07	9.5	.118
Alkali chlorides	13.8		14.0		2.4	
Potassium oxide	.....		1.7		.....	
Sodium oxide	.....		6.7		.....	
Total	250.2		655.7		160.1	
Silica, iron and alumina by difference	17.9		12.4		12.6	

Examination for potassium, showed its presence in all three waters. Determined as grams per ton.

(Signed) L. KIRSCHBRAUM.

Made at the Chemical Laboratory of the University of Michigan, E. D. Campbell, supervising.

An Ishpeming mine water, coming out of a diamond drill hole at a depth of 825 feet, gave the following results, which are quite different from the Vulcan mine water, and more nearly like surface waters:—

1.	2.	3.	4.
Lime as carbonate	55.8	(Oxide determined)	31.3
Magnesium as carbonate	17.0	" "	8.1
Iron and alumina carbonate	.5	" "	.7
Requiring CO_2 33.2		" "	34.3
Total encrusting solids	73.3		
Chlorides as sodium chloride	56.2	Chlorine determined	34
Sulphates as sodium sulphate	67.0	SO_3 "	33.4
Total corrosive solids	123.2		
Silica	10.5		
Water of crystallization[1]	3.2		
Excess of CO_2	1.1		
Combined CO_2	33.2		
Sodium chloride	56.2		
Organic matter by difference from ignition loss	19.9	19.9. Ignition loss	113.6
Total by computation	229.1		
Total by evaporation at 105° C	232.2		
Difference (minor errors, extra weight of potash over soda and undetermined)	3.1		

[1]The sulphates are probably in large part calcium sulphate, etc., and the soda correspondingly carbonate, reducing the amount of crystallization water.

Analysis by Kirschbraum, computation by Lane.

IRONWOOD.

From Ironwood, Dr. Vaughan has tested three kinds of water. The Montreal river, which is the public water supply, Nos. 130, 180; Pine Lake, 181, and various wells, 153, 188, etc., as follows:—

(The inorganic residue is probably, in part, silt.)

IRONWOOD.

Location.	Pine lake.[1]	Well.	River.[3]	River.[4]	Well.[5]	Well.[6]
Number	181	153[2]	130	180	188	194
Date	9 1 93	4 29 90	1 25 92	9 20 93	8 8 93	6 29 93
Color	yellowish			yellowish		
Odor	musty					musty
Reaction					feebly alkaline	
Hardness	9°	4°	6.5°	7°	8°	6.5°
Total residue	550	117.5	190	540	212	850
Inorganic residue	470	70.0	100	490	200	350
Organic residue	80	40.5	90	50	12	500
Cl as Na Cl	1.0	9.9	5.6	0.50	3.0	44.58
Permanganate reduced			46.136	12.5	12	
Free ammonia	0.018	0.176	.103	0.08	0.10	0
Albuminoid ammonia	0.30	0.248	.116	0.35	.20	.066
Nitrates		2.315	trace		traces	large amount
Nitrites		2.687	trace		traces	.90
Number of bacteria in 72 hours	500	12	960	250	600	450

[1]Microscope shows vegetable fibres and algæ.
[2]Duplicate number in Vaughan's list—Microscope 100 diam.—Brownish algæ and particles of inorganic matter.
[3]Sulphate trace—Microscope—Fresh water algæ.
[4]Microscope shows vegetable debris.
[5]Indeterminate granules; bacteria.
[6]Microscope shows vegetable fibres, Diatoms, etc.

IRONWOOD.

Location.	Waterworks.		Waterworks.	Filter.	Well.
Number	199[1]	200[1]	201[2]	222[3]	229[4]
Date	6/17/93	6/10/93	6/4/93	7 27/94	8/23 94
Color	brownish red	brownish red	brownish red	slightly yellowish	slight milkiness
Odor					
Reaction	slightly acid	slightly acid	slightly acid	alkaline	slightly alkaline
Hardness	2.5°	2.5°	2.0°	5°	6°
Total residue	75.0	75.0	75.0	90	170
Inorganic residue	12 5	12.5	12.5	64	100
Organic residue	62.5	62.5	62.5	26	70
Cl as Na Cl	5.0	5.0	5.0	1.98	7.42
Permanganate reduced		0.0			
Free ammonia	0.052	0.075	0.0084	0.33	0.018
Albuminoid ammonia	0.10	0.18	0.0528	0.51	0.200
Nitrates	0.70	0.6	0.6		trace
Nitrites	1.80+	8.0	trace		faint trace
Number of bacteria in 72 hours		384	231	liquefaction	1,000.

[1]Microscope shows bacteria—Diatoms—Monads.
[2]Microscope shows Diatoms—threads of bacilli and Desmids.
[3]Microscope shows vegetable debris and bacteria.
[4]Microscope shows small deposit of inorganic matter, vegetable debris, and a few Infusoria.
In Nos. 199 and 200 the reaction was positive,—the water dangerous. The brownish red color is due to swamp water, and humic acid, as the reaction shows.

IRONWOOD.

Location.	Well.	Well.	River.
Number	2311	2322	2333
Date	8 24 94	8 24 94	8 27/94
Color	milky	slgt. milkiness	brown
Odor	stale, musty	.....	.....
Reaction	feebly alkal'e	slightly alk'e	slightly alk'ne
Hardness	7°	6.5°	3.5°
Total residue	200	210	120
Inorganic residue	150	140	30
Organic residue	50	70	90
Cl as NaCl	4.12	4.95	1
Permanganate reduced	.....	.....	.....
Free ammonia	0.18	0.01	traces
Albuminoid ammonia	0.191	0.12	0.18
Nitrates	trace	traces	faint trace
Nitrites	large amount	large amounts	.....
Number of bacteria in 72 hours	800	200	120

[1]Trace of sulphates. Vegetable debris, diatoms, algæ, infusoria. Inorganic matter.
[2]Microscope shows inorganic matter, bacteria, algæ.
[3]Microscope shows inorganic matter, a few algæ. Desmids.

Location.		Well.[2]
Number	2531	
Date	2/7/95	4/29/90
Color	.....	.....
Odor	.....	.....
Reaction	alkaline	
Hardness	15°	4°
Total residue	400	117.5
Inorganic residue	340	70.0
Organic residue	60	47.5
Cl as Na Cl	3.30	9.9
Permanganate reduced	.....	.....
Free ammonia	0.005	0.176
Albuminoid ammonia	0.04	0.248
Nitrates	trace	2.315
Nitrites	.....	2.687
Number of bacteria in 72 hours	.....	12

[1]Trace of sulphates. Microscope shows deposit chiefly inorganic matter.
[2]Microscope shows algæ, Infusoria, vegetable fibres, and inorganic matter.

SAULT STE. MARIE.

Location.			
Number	89[3]	100[1]	101[2]
Date	10 28 90	11 17 90	11/17/90
Color			
Odor			
Reaction			
Hardness	2°	5°	4.9°
Total residue	89	153	107
Inorganic residue	21	117	59
Organic residue	68	36	51
Cl as NaCl	3.30	6.6	8.25
Permanganate reduced	0.632	5.99	5.372
Free ammonia	0.224	0.058	0.05
Albuminoid ammonia	0.168	0.104	0.12
Nitrates	very faint trace	0.77	0.965
Nitrites	0.1085		very slight trace
Number of bacteria in 72 hours	2,500	7	12

[1]Sulphates 5. 46. Microscope 100 diam.: Colorless amorphous matter, yellow amorphous matter, crystals,—algæ.—Desmids. 500 diam.: Colorless amorphous matter, yellow amorphous matter, crystals of Na Cl. Diatoms. Sciadium. Compsopogon.

[2]Microscope 100 diam. Colorless amorphous matter. Fibres, algæ 500 diam. Colorless amorphous matter, fibres. Draparnaldia.

[3]Microscope 100 diam. Algæ, germs, animalculæ, yellow amorphous matter. Draparnaldia and other algæ. Zoogloea, Paramecia, red spores of algæ, yellow amorphous matter, positive reaction.

AMASA.

Number	158[1]	159[2]	160[3]	161[4]	162[5]
Date	11 3 92	11 3 92	11 3 92	11 3 92	11 3/92
Color		slightly turbid			yellowish
Hardness	8.8°	9.7°	13°	7.5°	9.50
Total residue	100	200	190	420	110
Inorganic residue	75	170	150	295	80
Organic residue	25	30	40	125	30
Cl as NaCl	12.5	6.7	1.1	1.1	1.2
Sulphates		trace		heavy traces	trace
Permanganate reduced	20.54	25.28	31.60	18.96	32.5 48
Free ammonia	0.016	0.032	0.036	0.016	0.02
Albuminoid ammonia	0.113	0.36	0.15	0.23	0.23
Nitrates		heavy traces			
Nitrites		heavy traces			
Number of bacteria in 72 hours	44	liquefied	liquefied	liquefied	liquefied

[1]Microscopic appearance: Pigment granules, carbonate of lime, vegetable detritus.
[2]Mass of pigment, inorganic crystals, diatoms
[3]Microscope shows pigment granules, woody fibre. Bits of cotton fibre.
[4]Woody fibres. Pigment granules. Fresh water algæ.
[5]Under microscope. Pigment granules. Diatoms.

AMASA.

Number	163[1]	164[2]
Date	11 3 92	11 3 92
Color		
Hardness	9°	10.2°
Total residue	460	170
Inorganic residue	270	120
Organic residue	190	50
Cl as NaCl	7	2.9
Sulphates		faint trace
Permanganate reduced	28.62	44.08
Free ammonia	0.026	0.03
Albuminoid ammonia	0.24	0.24
Nitrates		
Nitrites		
Number of bacteria in 72 hours	countless	innumerable

[1]Cotton fibres. Indeterminate granules. Carbonate of lime.
[2]Pigment granules, algæ, woody fibre, reaction with inoculation positive, the previous analyses negative.

The Upper Peninsula being as yet a comparatively undeveloped region, there are many wells which are very shallow and superficial. The Amasa analyses are probably of this character. The hardness, like that of Iron Mountain, is noteworthy, and suggests that the surface deposits may have come largely from the east rather than the north.

At times, however, the surface deposits and wells in them, are quite deep.

At Sidnaw, wells go through 100 feet of quicksand. Schwartz Brothers at Pentogan, T. 42 N., R. 34 W., put down a well 4 feet by 4, 43 feet deep, through till (stone, gravel, and loam), at 32 feet a two foot seam of coarse sand was dry, at the bottom a quicksand was encountered, and drilling to a depth of 195 feet encountered nothing but quicksand.

On the other hand, at the Mass City brickyard, a well over 200 feet deep encountered nothing but clay. The surface deposits of the Upper Peninsula are quite irregular in distribution. On the Copper Range, just north of the Tamarack mine there is a large deposit of irregular gravel, with marked kettles, a sort of kame deposit, probably in an angle in front of the continental ice sheet. The same phenomena are repeated at Wheal Kate south of the Atlantic mine, and for a long ways south on the crest of the range, while the country not over 600 feet above the lake has been more or less worked over by the former extension of Lake Superior, and is liable to be clay with streaks of gravel or sand along old terrace lines. The areas of Laurentian rocks are large areas of bare knobs with pocket swamp between. On the whole, large areas of the Upper Peninsula and many of its streams have very soft water, which is an important item in many manufactories.

About 3° to 4° hardness is as soft as is to be expected.

I have previously remarked that the structure of the Lake Michigan shore belt is favorable to flowing wells, and that there is a probability that such wells drawing from the Potsdam sandstone will have fairly soft water. The structure of the Lake Superior shore, on the other hand, is not favorable to flowing wells east of Marquette. From Marquette around to Pequaming some should be obtained in the sandstone that skirts the Huron mountains. Thence to the end of Keweenaw Point, flowing wells need not be expected, though they may perhaps, be obtained in the low belt of land marked by the Sturgeon and Otter, Torch lake, Gratiot lake, and Lac Labelle.

We may insert here appropriately the following analyses:—

WATER ANALYSES NEAR CALUMET AND HECLA SMELTER, TORCH LAKE.

	2	3	4
Suspended sediment slight			
Silica	3.7	9.5	24.8
Iron oxide (exists as carbonate) and alumina	2.7	1.1	1.5
Calcium sulphate	5.8	7.0	2.0
Calcium carbonate	47.7	79.8	79.1
Magnesium carbonate	80.5	31.2	21.2
Sodium chloride	21.3	10.7	4.8
Potassium chloride	trace	trace	0.8
Nitrates	trace	.085	K_2CO_3 1.3
Difference (organic or undetermined matter)	34.1	9.0	1.4+
Loss on ignition direct	(23.1)	(14.3)	
Total solids	145.8	148.3	137.0

Parts per million.

These three analyses were all by G. L. Heath.

2. 10/1/1900, from the outside casing, down into solid stone, in parts per million.

3. Water from 80-foot wells at the C. & H. smelting works, Sept., 1900, driven just to sandstone, through the following strata:—

	Thickness.	Depth.
Soil and reddish sand.....	6 to 10 ft	6 to 10
Red hard pan.....	6 to 10 ft	16 to 20
Clear white beach grit, some pebbles and boulders	50 to 60 ft	78 to 88
Gravel and red sandstone.....	2 ft	80 to 90

Wells from the base of the drift are characteristically harder and have less salt, the total solids being about the same, yet this water though about twice as hard as Lake Superior, is only about half as hard as a normal Lower Peninsula water.

4. A driven well sunk in the beach near the Calumet & Hecla Mining Co.'s pumping station, on the west shore of Keweenaw Point, is evidently not at all Lake Superior water, but much like No. 3 and drift water. The water must come from the land side, and in fact, has a head of one foot above the lake. It illustrates the same principle as that of the well known fact that fresh water can often be found by digging down into a salt water beach. Outside the casing of the 500-foot well, comes a water very similar but with slightly less salt. The 1,500-foot well, it is said, never struck salt water, or indeed, very much water anyway, at the bottom. This 1,500-foot well, is, however, now filled up several hundred feet, so that it is now pumped (air lift or Pohlé system), the water coming from the first 500 feet. There was also a well at Mills, 500 feet deep, furnishing water of the same composition as that from the deep one.

Beginning from the end of Keweenaw Point, however, the conditions of strata dipping toward the lake are once more favorable to flowing wells clear to the Wisconsin line. I accordingly favored putting down a well near the lake shore at Freda, the stamp mill site of the Copper Range Company, Sec. 25, T. 35 N., R. 35 W. The results were disappointing. It was 18 feet to bed rock, and the well is said to have flowed slightly in the first 100 feet,—possibly from the surface deposits. The strata were red all the way down, sandstone but more or less basic, calcareous and much cemented, and this feature probably accounts for the relatively poor yield of water, and more or less shaly. In particular, from 910 to 950 feet, the beds were shale, making a regular red mud under the drill and underneath this the water was decidedly brine. The record is given below. It is obvious that this well is important in many ways. It indicates that, as was long ago held by [1]Irving, the sandstones east and west of the Copper Range are not of the same character, the character of this Freda water being much more like those of the deep waters of the Copper Range than like that of the Lake Linden well.[2]

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[1]Copper Bearing Rocks, chapters V and VII.
[2]Above, pp. 143, 163.

RECORD OF FREDA WELL.

Drilled by Chas. Coryell for Champion Mine.

Surface, muck, sand, etc., thickness, 18; total, 18.
Temperature of strong spring near by, 45° F.
Surface puddles, 50° F., June 22, 1902.
Top beds, dark maroon sandy shales, with much basic matter.
Water ever since, surface water not entirely cased off, water came to surface one day, in first 150 feet, but only once.
Temperature at top of water, 45.5° F., at about 100 feet.
March 5, at 150. Cased.
Water level about 50 feet down at 500-600 feet after stopping the drill over Sunday, March 28, at 400.
Temperature observed by Sheldon 51°, at 480; thermometer, 9111.
Temperature observed by Sheldon 51.5°, at 550.
Temperature observed by Sheldon 51.5°, at 636.
Alternate hard and soft streaks at 600.
Temperature after 12 hours suspension of work, 50°, at 730.[1]
Temperature after 8 days suspension of work, 49°, at 730.
Red shale, 40, 950.
Average speed, 1 foot in 3 hours.
June 22, finished at 970 to 950 feet.
Water level at 100-150 feet below ground on Monday, and bailing 18 to 20 times made no appreciable difference in the height.
Temperature, 49° at 730 feet.
Temperature at bottom, 55° (950), by 9109 Greene's thermometer.
Temperature 55.6° at bottom by 9111.
The temperature observations are not satisfactory, but the increase of 4° to 4.6° in 950—480=1° in 80 feet, to 1° in 87 is about equivalent to the total increase of 55.6° to 55°—45° to 43=1° in 85 feet to 1° in 80 feet.
The water from the bottom June 22, was found to have a sp. gr. of 1.07, and the sample taken for analysis a week or two before gave Dr. Koenig: sp. gr. 1.0511.

	Grams per kilogram.
$Ca\ Cl_2$	44.51
Na Cl	19.29
K Cl	0.56
Mg Br	0.24
Mn	0.57
	65.47

The Midland Chemical Co. also tested the same (Jan. 23, 1903) and found sp. gr. 1.049, Br .35 grams per kilogram, equivalent to $Mg\ Br_2$ .40.
This relative to the specific gravity is about as strong as the Midland water, and reminds one at once of the waters from the Tamarack and Quincy mines given above.

[1]Observed by driller, perhaps warmed too much in putting in and out. Thermometer at those low temperatures must be handled very promptly as the drill house is very hot often.

To compare with the Freda water, the Quincy water, and the Tamarack water, we have the following interesting analyses of the water from the bailer of the Vertical or Whiting shaft of the Calumet and Hecla, 4,960 feet deep. The water pumped from the Hecla end of the mine at much less depth, is "even more saline." These waters are in contrast with the shallower carbonated waters, say those of the Winona or Arcadian. It is noteworthy how small is the percentages of sulphates, as well as carbonates. That, to my mind, militates against any theory of origin of these deposits from sulphides. The minute quantities of nickel, copper and zinc with iron, point rather to olivine, or some such ferro-magnesian (femic) silicate as the original source.

Details of probable compositions in sediment.	Mine water. C. & H. Vert. shaft.		Atlantic ocean.
	Grams per liter.	Grains per U. S. gallon.	Grains per U. S. gallon.
Insoluble silica	.0222	1.29	.....
Insoluble oxide of iron	.0127	.74	.....
Dissolved silica (SiO_2)	.0033	.19	.....
Dissolved chloride of iron	.0045	.26	.....
Zinc chloride (with trace nickel)	.0290	1 69	.....
Copper chloride ($CuCl_2$)	.0015	.26	.....
Magnesium chloride	.0875	5.10	276.5
Sodium chloride (salt)	1.88	109.37	1.522.85
Potassium chloride	.074	4.31	53.25
Potassium bromide (in ocean only)	.....	.....	33 65
Calcium chloride	3.138	182.87	90.10
Calcium sulphate	.0555	3.23	.....
Sodium sulphate (in ocean only)	.....	.....	261.30
Calcium carbonate (dissolved by free carbonic acid)	.248	14.46	.....
Loss on ignition (actual determination)	1.08	63.0	.....
No lithium. Undetermined balance traces carbon, etc.	.....	.....	.....
Sum of all constituents	6.65	386.77	2,237.65
"Total solids" on evaporation as weighed $\{^{354+}_{383+}\}$	6.32	368.5+	2,238.72

G. L. HEATH.

While, therefore, there is a possibility of artesian wells along the Lake Superior shore of Keweenaw Point and the Porcupines, unless they are not deep the water is likely to be a mineral water,—perhaps even valuable for the manufacture of bromine and other salts.

WATER POWER.

In regard to the question of water power, that subject has been in the hands of Mr. R. E. Horton of the U. S. Geological Survey, to whom I have given various assistances at different times. Mr. W. M. Gregory

and W. V. Savicki have also aided him. The result of his work in this state will be found in the U. S. Geological Survey Water Supply Papers, No. 30, No. 49, pp. 239-260; No. 65, p. 315; No. 75, p. 111; No. 83, pp. 241-297; and the Michigan Engineer for 1901. In an official letter, correcting No. 83, we have the following discharge measurements on the Au Sable river at the gauging station at Bamfield, Michigan:—

Date.	Hydrographer.	Gage height (feet).	Discharge (sec. ft.).
August 14, 1902	Horton & Gregory		1,133
August 26, 1902	W. M. Gregory	0.82	1,026
September 17, 1902	W. M. Gregory	.80	998
October 7, 1902	W. V. Savicki	0.72	981
March 6, 1903	Horton & Roundy	1.10	1,176
March 13, 1903	E. P. Roundy	2.60	1,999

LIMESTONE.

LIMESTONE.

The study of the limestones of the northern part of the Lower Peninsula has been continued by Mr. Grabau, who is preparing a monograph upon them. Over 124 forms of the rich variety of fossils have been figured for reproduction. These studies have great scientific interest, as Michigan lies between and connects the eastern and western, or as Schuchert calls them Cumberland and Dakota Devonian seas.[1] They have also, however, a practical bearing. The limestone itself is of increasing value. It is shipped to Manistique and Gladstone to make acetate of lime; it is largely used in sugar manufacture. It is the raw material now of the Elk Rapids Portland Cement Co. which has recently consolidated with the Bay Shore Lime Co., as well as the Alpena Portland Cement Co. The rock Portland cements, are, I am told by practical engineers, no stronger, but smoother, and able to go farther than the marl cements.

Dr. Grabau writes:—"We still need about as many more illustrations as we have already made, and I trust you can give us an appropriation of $150.00 or $200.00 for this year. I will fully justify the expenditure in the report, when I think that I can easily prove the knowledge of the fossils is absolutely essential for the finding of limestone deposits of economic value and I also think that I can show that by means of fossils we can trace out anticlines in the limestone region, which may lead to the discovery of gas."

The development of the limestone business is illustrated by the Bay Shore Lime Co., recently consolidated with the Elk Rapids Portland Cement Co., concerning which the following facts are given. We have also, through the courtesy of the Elk Rapids Portland Cement Co., copies of analyses of their raw materials, showing their excellent character. The limestone is the Petoskey limestone, and the analyses are essentially similar in character to analyses given in 1901, 1902 reports. The analysis of the coal is given later.

BAY SHORE LIME CO.

"The Bay Shore Lime Co. is a corporation of this state, capitalized for $250,000.—$200,000 common and $50,000 preferred stock. It has been in business for the past 16 years at its present location and has built up a business which for several years past has paid good dividends on the capitalization. Its output of lime for the past ten years has increased from 16,500 to 118,517 barrels per annum, indicating a steady and profitable growth during the panic of 1892 to 1897, when other lime companies did very little. This is accounted for by the high grade of lime made from the rock in their quarries, which seems to be superior in quality and commands a better price than other limes in a great many markets.

[1] Am. Geologist, Sept., 1903, pp. 137 to 156.

"Mr. Sly, the president of the company, makes a sworn statement of their profits for the year 1901, after paying all salaries, repairs, etc., of $28,280.87. With the addition of its present stone-crushing plant, recently built, and two new kilns which are now nearly completed, the earnings of this company will be easily increased to $40,000 per annum, and can be made to exceed that amount by natural growth.

"The property of this company is all located at or near Bay Shore on the Pere Marquette railroad and Little Traverse Bay, seven miles west of Petoskey. They have four (4) large lime-kilns in operation and two building which will make 140 barrels of lime per day each. Their property consists of nearly nine (9) hundred acres of land, more than half of which is underlaid with limestone with a workable depth of from fifteen to sixty (15-60) feet. This is divided into several grades, one for building lime, the others for use in blast furnaces, wood alcohol and beet sugar plants, tanneries, paper mills, for making calcium carbide and Portland cements."

LIMESTONE.

Ig'n loss	49.91
Silica	3.37
Alumina	2.57
Iron oxide	
Lime	51.43
Magnesia	.50
Sulphur anhydride	.60
	100.38

SHALE.

Ig'n loss	17.50
Silica	56.00
Alumina	13.50
Iron oxide	6.50
Lime	2.50
Magnesia	2.00
Sulphur anhydride	.80
	98.80

W. G. BANKS.

"The limestone we use here is located about 2½ miles south of Petoskey, Mich., on the Pere Marquette R. R.

"The shale is located on Pine lake about 8 miles up from the city of Charlevoix, and comes to us by boat."

The development of the Detroit and Mackinac R. R. from Alpena toward Cheboygan, has opened a number of quarries which are in the same general horizon as Petoskey and Alpena.

Mr. A. N. Clark of the Alma Sugar works has been kind enough to give us results of a number of tests, from which it appears it is possible to get

calcium carbonate by the car load with but 2% or 3% of deleterious impurities. He writes, giving analyses below:—

Alma, Mich., Nov. 18, 1903.

.....

We have been using some Onaway limestone here at the factory. Some is good and some is poor. Runs from 90 to 98% $CaCO_3$. Some of it is of a rusty color and contains 6 to 8% sand and iron.

Yours truly,

A. N. CLARK.

PETOSKEY LIMESTONE.

A. N. CLARK, ANALYST.

	March, 1902.	April 28, 1902.[2]	
		Stratum 1.	Stratum 2.
Organic	.62[1]	.....	.....
Insolubles	.44	1.03	1.21
$Al_2 Fe_2 O_3$	.43- mainly Fe_2	.80	.70
$Ca CO_3$	96.58	83.05	90.62
$Mg CO_3$	2.-	15.11	7.41
$S O_3$	bare trace	.....	.....
	100.05	99.99	99.94

[1]Hydrocarbon limestone smelling strong of petroleum when struck, has shale like appearance. Fine texture. Small sample sent.
[2]In kegs, two strata.

LIMESTONE NEAR LAKE HURON—NORTH OF ALPENA (NORTHEASTERN MICHIGAN).

	D-1.	E.	A.	D-2.	B.	C.
Insoluble	2.80	1.25	8.60	1.61	1.75	.40
$(O_3 Fe_2 Al_2) O$	.40	.40	1.40	.....	.....	.....
$Ca CO_3$	96.13	96.47	88.86	94.77	97.70	96.36
$Mg CO_3$	.68	1.60	.38	1.28	.60	3.—
Undetermined and $H_2 O$	.....	.82	.76	2.34	.....	.24
	100.61	100.—	100.—	100.—	100.05	100.—

COMPOSITE SAMPLE OF ALPENA LIMESTONE FROM ALMA SUGAR CO. (AUGUST, 1902.)

Insoluble & $(Fe_2 Al_2)O_3$	1.30	Insoluble and difference	1.—
$Ca CO_3$	97.60[1]	$Ca CO_3$	[1]96.—
$Mg CO_3$	1.09	$Mg CO_3$	3.—
	99.99		100.—

[1]Checked three times volumetrically with permanganate gave 97.66 Ca C O_3 or 97.55. In car No. .146 gave 96.6 $Ca CO_3$.

SAMPLE OF LIMESTONE FROM ONAWAY.

Organic matter and moisture	1.30
$(Fe_2 Al_2)O_3$	.40
$Ca CO_3$	97.—
$Mg CO_3$	1.70
	100.40

The following analyses also by Mr. H. R. Browne, are of interest, especially the very complete one of the Bellevue quarry in the carboniferous limestone, because this property has recently been purchased by the Burts of Saginaw, for a Portland Cement plant, and it is unusually complete.

BELLEVUE.

Soluble in H Cl:		
$Si O_2$	0.1208	
$Al_2 O_3$	0.1008	
$Fe_2 O_3$	0.2093	
Fe O	0.2916=	.4698%
$P_2 O_5$	0.2692	
Mn	0.0449	
Arsenic	trace	
Ca O	53.300	
Mg O	.483	
$C O_2$	42.15	
$S O_3$	.098	
	97.0676	97.0676
Gangue insoluble in H Cl:		
$Si O_2$ soluble in $Na_2 CO_3$	.354	
Insoluble	1.63	
S as pyrites	.175	
$Al_2 O_3$	.369	
Ca O	.021	
Alkalies	.062	
	2.654	2.654
Organic matter	.1334	.1334
		99.8550

Three different beds of the Christiancy quarries in Monroe County show both a high grade and a magnesian limestone.

CHRISTIANCY QUARRIES.

	1	2	3
Insoluble (silica) in H Cl	0.49	0.61	3.31
Iron and alumina oxide	0.13	0.15	0.35
Calcium carbonate	97.59	97.64	77.78
Magnesium carbonate	1.66	1.55	18.48
	99.87	99.85	99.92
Difference (organic, etc.)	.13	.15	.08

Analyses by H. R. Browne.

CORRELATION ACROSS DETROIT RIVER.

INTRODUCTION.

Prof. Sherzer for us, and the Rev. Thomas Nattress of Amherstburg, on the Canadian side, are gathering very interesting information about the limestone along the Detroit river, upon which the various well records which I am able to turn in from my work from time to time, will throw much light.

I quote a letter of much interest from Mr. Nattress. The change of dip noted by Mr. Nattress, may be of importance in collecting oil. The Anderdon quarries near Amherstburg and Sibley quarries near Trenton, both dip southwest and seem to lie on the northeast side of a synclinal tongue of the Dundee or Corniferous limestone. A fault may bow the southwest side. To the north of them there should accordingly be a subordinate anticlinal or pitching fold, passing through Wyandotte.

St. Andrew's Manse,
Amherstburg, Ontario, Feb., 1903.

Dr. Alfred C. Lane,
State Geologist for Michigan,
Lansing.

Dear Sir:—The accompanying comparative statement of strata in (1) Monroe county, (a) "Monroe," and (b) "Dundee," and (2) Anderdon Tp., Essex county, Ontario, may not be without interest to you. I have a hope it may be of some service in getting at our problem in determining the relationship of said strata. I may say that the elevation of surface of white sand rock, here, is 552.00 above mean tide at New York. Mr. Dixon and I will ascertain the elevations of the successive outcrops of the Anderdon quarries. * * *

I believe I have found the point where the variation of dip begins. All I shall say just now is that I am obliged to admit an error in my former assertion that the sandstone (which is indeed "south of") is "superincumbent upon the Corniferous described in my paper." It is *not superincumbent.* This I now know. When, however, you become acquainted with the locality of the several outcrops, and note the very short distance in which the change of dip takes place, you will not be much surprised at my mistake.

There still remains to be explained the presence of the gray dolomite superincumbent (in the Anderdon quarry) upon the Dundee (Corniferous) limestone. This gray rock is in no way to be mistaken for Hamilton.

Very truly yours,
THOMAS NATTRESS.

[1]Tests made by Mr. Nattress and myself in 1904, (letter of July 13), prove this *not* to be dolomite, though not so pure calcium carbonate as layers below. I expect to have the matter treated more fully in the Wayne county report.

	I. The Monroe beds:[1]	Page.	II. The Dundee:	Page.	III. Anderdon:
Above the Sylvania.	(1) Dip. N. W. to N. (30 or 40 feet per mile.)	45	(1) "General dip to the N. W."	37	(1) Dip. "The approximate dip is ⅝ of an inch to the foot, S. by W."
	—W. 25° S. ("Water collects at S. W. corner.")	79	—"Christiancy quarry * * * 24 ft. per mile * * * W. N. W."	37	
	W. by S.	82			
	—"A fold * * * a high local dip"	87	—"Pulver quarry * * * 119 to the mile"	37	
Below the Sylvania.	—"Stripping increases to S. W."	92			
	—"Rock dips in four directions, from 2° to 5°".	95			
	—N. 61° W.	95			
Above the Sylvania.	2. Color:		2. Color:		2. Color:
	—"Gray to drab"	46	"Light gray to brown * * * running into blue"	39	The only rock that may be described as "drab" here is *not a dolomite*, but the pure limestone, lying between the *gray* rock above and the *brown* dolomite below; unless it be the rock next below the brown.
	—"Where weathered * * * of almost a chalky whiteness"	46			
	—"A light colored, finely laminated"	79			
	—"A drab and brown dol."	80	Cf. Orton, Ohio, "Is light colored, gray, drab and brown."	39	
	—"A firm grained drab dol., smooth"	91			
	—"Buffish gray"	82			
	—"Dark when damp, but drying to a light gray"	86			
	—"Buff"	87			
Below the Sylvania.	—"A light or dark drab dolomite"	92			
	—"A gray or drab dolomite"	92			
	—"A drab dol." * * * "Deep blue"	94			
	—"A gray to creamy white dol."	95			
	—"A light drab dol."	95			
	—"* * * covered with a black carbonaceous deposit"	95, 96			
	—"The rock weathers to a soft mealy substance of a creamy color"	97			
	Cf. Above and below Sylvania sandstone. "Bituminous matter is present locally, but does not impregnate the rock as in the case of the Dundee"	46	"Most of the beds have a strong oily odor, and semi-fluid bituminous matter frequently collects in the cavities of fossils"	39	None of our rock is impregnated with bituminous matter. Semi-fluid bituminous matter does not occur in cavities of fossils. There is a slight odor of oil in brown dol. from bed of river. There are thin layers of black bituminous substance in the same strata, one of them half an inch thick.
	Cf.	95, 96			
Sylvania.	3. Peculiarities:		3. Peculiarities:		3. Peculiarities:
	Weathering to a "chalky whiteness"	46			Some of our chert weathers chalky white,—some of our high grade limestone is thin bedded. Nothing brecciated; unless wavy surface layers of pure limestone. No ripple marks identified; nor mud cracks. No large concretionary bodies. No
	—"Thin bedded"	47	"The upper beds are thin bedded and shattered"	39	
	—"Brecciated beds"	47			
	—"Ripple marks and mud cracks"	47			
	—"Immense concretionary bodies"	47			

[1]Monroe County Report.

Above the Sylvania.	—"In places cavernous"	79	caverns. No ellipsoidal cavities, except where Favosites hemispherica has decayed away. No stylolites. No concretions observed
	—"Ellipsoidal cavities"	80	
	—"Peculiar stylolites"	89	
	—"Ellipsoidal concretions"	90	
	—"Thin wavy carbonaceous films traverse the rocks"	94	
	—"Between the strata are layers of a soft putty-like clay which hardens on exposure".	94	"Seams of clay very frequently separate the layers" 39
Below the Sylvania.	—"Breccia"	95	
	—"Sink holes * * * with diam. of 6 to 10 ft., * * * produced by solution of the dolomite"	114	
	—"The individual strata have very rough surfaces, covered with black carbonaceous deposit"	95, 96	"A two foot bed of chert at the Sibley quarry" 41
	—"Thin bedded fissured dol."	96	
	4. Essential characteristic: The typical dolomite layers show the normal proportions of lime carbonate and magnesian carbonate: from 50 to 55 per cent of the former and 42 to 43 per cent of the latter ingredient	pp. 46, 82, 83, 86, 87, 92, 95	4. Essential characteristic: —"Essentially a pure limestone" 38 —"Carbonate of magnesia * * * may run up to 25 per cent. 39 —"A very small amount of iron" 39
	5. Crystals: —"Small cavities carry celestite, calcite, and a little native sulphur"	80	5. Crystals.
	6. Strata: —"Thin bedded"	47	6. Strata: —"The upper beds are thin bedded and shattered" 39
	—"Strata average eight inches"	92	"Deeper layers * * * reaching a thickness of several feet" Cf. Orton, Ohio, "The individual beds may reach a thickness of five feet" 39
	—"Thin bedded fissured dol."	96	—"In the upper division * * * the beds seldom reach one foot in thickness" 39
	7. Fossils: —"A stratum of gasteropod molds and casts"	79	7. Fossils: —See p. 227, Dr. Rominger's list 227
	—"Generally quite poor in fossils"	222	
	—"Crinoids, corals and bryozoan remains are found occasionally" * * * "lamellibranchs rarely"	222	
	—Vide	pp. 223-225	—Fenestella, Polypora, Orthoceras, Gomphoceras, Nautilus, etc 227
	—"Conularia, Tentaculites, Stropheodonta, Orthis * * * Conocardium, Platyceras, and numerous gasteropods, lamellibranchs, trilobites, crinoids, cyathophylloid, and favositoid corals"	226	

Similar films observable near the juncture of brown dol. and true limestone (perhaps in both) in Detroit river bed. There is no clay deposit between layers anywhere.

—No breccia observed. Sink holes of small size; but in the true limestone (where it is a surface area) and *not in the dolomitic rock*. There are rough surfaces in the true limestone. (Also at certain elevations in the gray rock with black carbonaceous deposit.)

—But this is the peculiar formation known as *crystallites*.

—There is an apparently thin bed of chert in the brown dolomite (which may be "a fine crystalline massive quartz").

4. Essential characteristic:

—Gray rock $CaCo_3$. $Mg\ CO_3$.
60 903 36 463.

—Brown rock 57 28 , 41 15.

—Gray rock $Fe_2\ O_3$. $Al_2\ O_3 = 0.230$.

—Brown dol. " " $= 0.32$.

Between these is pure limestone.

5. Crystals:

In the gray rock, the characteristic crystal is *dog tooth spar*, small to large in size, and fluor crystals, in cavities; fluorite and *calcite* in light seams. In the brown dol. the characteristic crystals are *Scalenohedra of calcite* (carbonate of lime). Also *Strontianite* and *celestite*. Then there is the stratum of "minute closely cohering grains of quartz," = Sylvania.

6. Below:

Your Dundee limestone corresponds closely with our pure limestone in bedding.

—The gray rock beds measure (in descending order) 2,[1] 8, 4, 8 and 10 feet.

—The brown dolomite is not thin bedded, though no measurements are to hand.

7. Fossils:

—See pp. 124, 125 of my paper in 1902 Bureau of Mines Report (Ontario), for fossils in the gray rock.

—See pp. 126, 127, b. for fossils of brown dol.

[1] Examination of a fresh break of this ledge after observing the same stratum on Pelee Island indicates thin bedding, not at first evident.

Notes on the Fossils in these Different Beds.

The "stratum of gasteropod moulds and casts" (p. 79) in bed A of the Woolmith quarries, above the Sylvania sandstone, *though differing entirely in color,* would remind one of a stratum of our brown dolomite, exposed in Detroit river bed, as to its gasteropod contents. The "occasionally" (p. 222) and "rarely" with reference to crinoids, bryozoans and lamellibranchs in the Monroe beds, apply here also; but do not apply with reference to our corals, especially in certain strata of the brown dolomite. *Tentaculites,* which you include among the fossils of the Monroe beds, does not occur here at all so far as observed, though it is abundant in the subsequent Hamilton formation, as at Bartlett's Mills and Arkona, Lambton county, Ontario.

Though there is a certain amount of identity between the forms found in the Monroe beds and the strata here, it would not appear to me to be greater than might be looked for from persistence of the fossil forms of one formation in the next later formation.

On the other hand, the Dundee fossils (p. 227) so far as enumerated, correspond very closely with our much longer list from the Anderdon quarries and the Detroit river bed exposures, a list that is made larger still when supplemented, as from "Geology of Canada, 1863," page 378.

But your Dundee is "essentially a pure limestone" (p. 38); whereas our high grade limestone appears to contain very few fossils, save a few cup corals and a few far-spreading Stromatoporoid, the low grade limestone (gray rock) above, and the dolomites below, being the fossil bearing strata.

(Signed) THOMAS NATTRESS.

In the Upper Peninsula, various well records, for which see the paper on Water Supply, have added to our knowledge of the geological column, with its heavy belts of limestone along the Lake Michigan shore. This has been treated in connection with the water supply.

Limestone Mountain, an interesting and isolated group of outcrops of the section up to and including the Niagara, has recently been made very much more accessible, by the line of the Mineral Range R. R. (D., S. S. & A.), which skirts the foot of it. It is so far from any other limestone, and so near points like Houghton, to which limestone is largely supplied, that I think it worth while to call attention to it. The Survey has done work upon it, which has never been published. This work was done very largely by W. L. Honnold, and a report on the fossils, written by myself over ten years ago, but the railroad and sundry new facts should be incorporated.

It was visited this year by Mr. A. G. Ruthven, who found it quite accessible, bare from recent fires, and with a limestone quarry proposed. Being so far from any other limestone, this might well be profitable, and I trust may be further studied in the near future. But I think it justice to Mr. Honnold that his work be given first, in addition to the fact that it will materially aid the next workers. I myself visited the district in June, 1894, and studied it with L. L. Hubbard and A. E. Seaman, having previously studied the fossils. We also visited other exposures of the limestone in two small hills on Sec. 7, T. 51 N., R. 34 W., which apparently had not been observed by previous geologists. It is not as high. All these hills rise from plains of flat clay apparently not unlike that at Mass

City and elsewhere referred to. The plains appear to correspond in level to the towns of Houghton and Hancock, being from 90 to 205 feet above the lake, the level of Upham's Beaver bay beaches. From this general level of about 210 feet, the hills rise often in steep wave cut bluffs, the higher hill on Sec. 7 is about 250 feet above Lake Superior, 852 A. T., the lower limestone thin bedded, the upper with a bird's eye effect, with *Murchisonias, Crytodontas,* Rhynchonelloids, bryozoa, and Alveolites.

Limestone Mountain itself is fully 400 feet above Lake Superior, 1,002 A. T., 250 feet above the plains and 150 feet above the highest sandstone outcrop. The lines of wave cutting are at 325 feet, 240 to 270 feet, and at 210 feet I estimate (barometer). In addition to the specimens collected by Honnold and described below, we collected specimens 155067 to 166016, which show Maclurea, Ambonychia, Orthoceras, Murchisonia, Pleurotomaria, etc. 16571 and 16572 represent the Niagara, the remainder being apparently, Trenton. The following is a quotation from letter of W. L. Honnold, dated July 14th, 1894:—

"The principal question to my mind is: Whether the contact exposed is between the limestone, i. e., Calciferous and the L. S. sandstone=Potsdam, or between the Lower Magnesian (=Calciferous) and Madison sandstone. That is whether the Madison sandstone and Mendota limestone exist here. The sandstone I exposed under the limestone compares well with the Madison (better than with the Potsdam) and it may be that if excavations were made further west, the Mendota limestone would be found, and still farther west the Potsdam."

It is clear we have here in a short space, a section from the Niagara limestone down. The Lorraine and Utica shales have not been discovered, however, and the Trenton has not been well differentiated from the Calciferous. It affords most excellent opportunities for careful paleontologic study, which would be of great interest in connecting Minnesota with the east.

In connection with the limestone business, one of the discoveries of most interest to me is that shown by the samples of the Manistique well,[1] of the belts of real limestone, not dolomite, from 80 to 107 feet down, which should be the first rock encountered in a belt passing two or three miles north of town.

So far analyses of Niagara limestone have generally shown dolomite, and the presence of belts of chemically acceptable limestone, would be valuable to the calcium carbide and calcium acetate industries.

CEMENT MATERIAL.

The exhaustion of our timber resources is a present fact to this extent, that for many uses it is already too dear. There is, therefore, a great activity in the development of materials to replace it.

The lime and cement business is, therefore, in a flourishing condition, and we have given some notes about the Bay Shore Lime Co., consolidated with the Elk Rapids Portland Cement Co. We have recently published a report, Volume VIII, on the cement business, and so we have only to add occasional notes as they may develop.

The Michigan Alkali Co., having sold their Bellevue quarry, an analysis of which is elsewhere given, have acquired land around Alpena (see 1901

[1] See pp. 140 to 141. It may be in this belt that the Osborn caves lie.

report), containing limestone. It is probable that salt may also be obtained, thus making an ideal place for soda manufacture. (Alpena News, 5/11/03.)

In Branch county[1] it is suggested that the marl of Marble, Middle, Bartholomew, Wing, Long, and Coldwater lakes may soon be utilized for cement manufacture by draining the same. The Quincy plant is now on Middle lake.

Marl beds are reported on Maple river near Brutus;[2] South Monterey near Allegan,[3] and borings have disclosed it at Saugatuck,[4] and Union Pier. It is probable that most of the lakes along the Lake Michigan shore, may have some marl, but it is doubtful if it is of high quality.

It must not be forgotten, however, that almost all of our surface clays are highly calcareous and worthy the name of marls, according to dictionary definition, though not according to cement factory usage. Bog lime is a much better term for what they call marl. In the clay analyses given later, there can generally be allowed about twice as much limestone flour as there is of calcium magnesium oxides. We see accordingly, that there is often about a fourth calcareous matter in such clays. It is not surprising, therefore, that specimens come in for my judgment, taken for marl. So they are, but not in the Portland cement man's sense. There are marl beds and calcareous clays near Port Huron.

In regard to the question as to the amount of pyrites permissible in a coal to be used in cement manufacture, we have the following:—

Elk Rapids, Mich., December 15, 1903.

Mr. Alfred C. Lane,
State Geologist.
Lansing, Mich.

Dear Sir:—Replying to yours of the 9th inst. I wish to thank you very kindly for Volume No. 8, which you are sending us, and if there is any charge for it please send me bill and we will remit.

We are pleased to give you the information desired in regard to analysis of coal, and the effect of sulphur and pyrites of iron in the same, upon the clinker. We have found in our practice here that on the average not more than 3/10 of 1% of the total sulphur found in the coal is retained by the clinker. This will vary a good deal according to whether the coal is finely or coarsely ground and whether a large or small amount of air is used in burning. By the use of a large amount of air, we found the pyrites of iron in the sulphur was blown out. We have also found that the use of a shale containing quite a high per cent of pyrites of iron in the form of knobs, after it is incorporated in the slurry and ground, causes us no particular trouble as far as the sulphur is concerned. This resulted because of the fact that the oxidizing in the rotary is such that all the sulphur is driven out or oxidized to a condition which is not harmful.

We found no more sulphur in the clinker made from shale than will be given by the materials themselves, burned with the flame containing no

[1]Detroit News, 8/23/1903.
[2]Petoskey Democrat, 7/4/1903.
[3]Grand Rapids Herald, 6/27/1903.
[4]Holland Sentinel, 5/9/1903.

sulphur. Of course, this is accomplished by careful burning and careful grinding of the coal.

Trusting this may be satisfactory, we remain,

Yours very truly,

ELK RAPIDS PORTLAND CEMENT CO.,

F. B. Moore, Sec'y.

Coal Analyses.

SHIPMAN CO.'S COAL (PITTSBURGH NO. 8) OHIO.

Volatile combustible	30.375%
Fixed carbon	46.175
Sulphur	5.09
Ash	18.36
	100%

CAMBRIDGE COAL, OHIO.

Volatile combustible	33.00 %
Fixed carbon	58.00
Sulphur	1.61
	92.61 %

W. C. CLARK CO.'S COAL, PITTSBURGH NO. 8, FROM OHIO.

Volatile combustible	36.455%
Fixed carbon	49.385
Sulphur	3.29
Ash	10.42
	100%

SUNDAY CREEK (WEST VA.) COAL.

Volatile combustible	35.19 %
Fixed carbon	49.55
Sulphur	1.30
Ash	13.96
	100%

WOLVERINE COAL, BAY COUNTY.

May 27, 1904.

Analysis of Wolverine No. 2 coal, by Dickman and Mackenzie, for Wickes Bros. Dried at 212 degrees F. Sample from car load lots.

H_2O	6.76
Volatile comb.	42.67
Fixed comb.	42.01
Ash	8.65
	100.10
Sulphur	3.50

B. T. U. 12,295.

This is the Upper Verne, according to Mr. Cooper.

Analysis of a coal from Bay City, Michigan.

Moisture	5.92
Volatile combustible	37.74
Fixed combustible	36.54
Ash	19.80
Sulphur	8.60

Sept. 14, 1903. E. D. CAMPBELL.
This may be the Lower Verne.

BUILDING AND ROAD MATERIALS.

The lumber supply of Michigan is not only approaching exhaustion, it is exhausted so far as the cheaper uses of wood are concerned. Instead of cedar blocks, plank, and corduroy roads, asphalt block, bithulithic or tar macadam, and macadam roads are coming in; instead of cedar fence posts, cement posts, and for building material instead of wood, brick or clay, sand or cement, concrete blocks, and concrete and steel constructions.

The asphalt block is made of Calumet and Hecla or Tamarack stamp sand, i. e., crushed quartz porphyry or felsite, cemented by asphalt. The following experiment on a limestone, a trap, and a conglomerate sand asphalt block was made, to show the relative durability.[1]

"The blocks were placed side by side near the periphery of a ten-foot marble rubbing bed, running thirty revolutions per minute. Each block was weighted, so that block and weights combined weighed forty-five pounds. They were all kept on the running bed forty-five minutes, sand and water being freely and properly supplied all the time. The limestone block was worn away one inch on its 4x12 inch face, the trap-rock three-eighths inch, and the conglomerate sand-block one-eighth inch. It is proposed to use the conglomerate sand in the factory mentioned above" (Detroit or Toledo).

The sand is shipped from the waste piles at Torch Lake to the factory at Toledo, and while water transportation is cheap it would seem as though a factory of these blocks could be started to good advantage at Lake Linden. This has been suggested.[2] The raw material could be improved by using the felsites of Mt. Houghton or the Bare Hills region[3] without doubt, which would not be decomposed as the wall rock of the copper lodes. But I do not think the advantage would pay for the cost of crushing.

The pavement of asphalt blocks is used in Pontiac and Ann Arbor and is well spoken of. It is also used in Kalamazoo. Occasional complaints are that the rock is crumbly under changes of temperature. Whether this is due to defects in the manufacture of particular lots I cannot say.

[1] Michigan Engineer, 1899, p. 110.
[2] Portage Lake Mining Gazette, October 22, 1903.
[3] See Vol. VI, Part 2, of Report of Geol. Survey of Michigan.

The "bithulithic" pavement[1] is meeting with much favor. It is essentially a macadam with a patent filler and binder of coal tar origin and bituminous nature. A full account will be found in the 1904 report of the Michigan Engineering Society. It has been used in Saginaw, Port Huron, Mt. Clemens, Bay City, Manistee, Kalamazoo and Pontiac. It should not be laid in cold weather. From the point of view of the economic geologist, the essential points are:

(1.) Like all macadams it must be well underdrained. On till or heavy clay a drainage two feet below the surface of road should be provided, and a bed of gravel or cinder, broken brick or other porous material laid.

The foundation proper is of 1 to 3 inches of broken stone, for which the various limestones of the State will do. The trap of the Upper Peninsula is better, and crushed field stone are usually all right. Layers of finer material should be laid on top, to fill the coarser material and a coat of bituminous cement applied. Then the surface coat of from 1¾ inch to 1-10 inch material mixed with cement is applied. Possibly stamp sand of the coarser grades could be used to good advantage here, and any way, a harder and less dusty rock like granite chips, crushed field stone or crushed trap is preferable to limestone for this top coat. A thin layer of stone chips is rolled into the surface, and this might well be waste jasper, crushed stamp sand, granite chips, or similar material, with which the State is well supplied. So far as raw materials are concerned Michigan should have good roads.

Perhaps an ordinary macadam might be converted by repeated sprinkling with crude oil into a somewhat bituminous macadam.[2]

As regards plain macadam and gravel roads I would call attention to the pamphlet "Modern Road Building,"[3] which, though an advertising circular for gratuitous circulation, contains many good hints, no matter what machinery may be used.

Road Materials in the Upper Peninsula.

The Upper Peninsula has a wealth of good road making materials. Around Ishpeming and Negaunee the waste rock of the iron mines, the "jaspilite," a red jaspery chert, is used. The chert makes a hard road and the iron gives it good cementing power. The main drawback is the bright red, paint-like dust, of which it is almost impossible to rid oneself. In damp weather these roads are fine, and a treatment with crude petroleum might be an improvement.

In some places the diorite, which is often the foot of the ore bodies, and makes most of the prominent knobs, is used. This is also a good material and the color is not so objectionable.

Northeast of Teal lake a crusher has been installed, crushing the gannister, or Mesnard quartzite. A road near the cemetery is finished with this. The same rock has been used near Marquette. It is very hard, but not tough, and does not cement so readily as some rock. There are also quantities of very fair gravel.

In the copper country the crushed trap of the copper mines is used and makes an excellent material. In a few places near the Allouez, broken conglomerate, which is practically broken felsite, is used. Both are among the best of materials.

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[1]See advertising literature issued by Warren Bros. of Boston and New York.
[2]Year Book, Department of Agriculture, 1902.
[3]Port Huron Engine and Thresher Co., Port Huron, Mich.

Quartzite is on the whole probably the most widespread of materials, but usually does not cement well.

Hard limestone is found at Manistique and numerous other points and has good cementing powers, but for a combination of toughness with cementing powers, it will be hard to find a rock to excel the copper country traps and the iron country "diorites" or amphibolites.

Clays and Shales.

As regards paving brick, I have repeatedly called attention to the waste of the coal mines as furnishing suitable raw material.[1] The coal measure shales, like those naturally exposed at Flushing, often make good paving brick. The neighborhoods of Grand Ledge and Williamston, and Jackson are also promising. The exposures along the east side of Huron and Sanilac counties and of the Antrim shales in the northern part of the Lower Peninsula, as at Boyne Falls will also be likely to prove satisfactory. The Antrim shales are the same as the New Albany shales of Indiana. In the Upper Peninsula some of the slates near L'Anse would probably be all right, if the cost of grinding were not too much.

In as much as we have recently issued a report on clays we have only a few notes to add.

At Mass City, on Sec. 9, T. 50 N., R. 38 E., close to the little creek that flows through the center of the section and about 800 feet from the C. M. and St. P. R. R. station, is the newly opened brick yard of the M. Van Orden Co. The brick are mainly light red. The bed of clay is some 190 feet deep as shown by borings,—all clay, but only the top 12 feet or so are now used. There are kettles of slightly sandier (6 per cent. sand) clay on top.

Analysis of clay from Mass City, by Elmer E. Ware, gave:—

Ann Arbor, Mich., Oct. 20, 1903.

SiO_2	52.12
Al_2O_3	14.95
Fe_2O_3	4.41
CaO	10.21
MgO	4.56
SO_3	.20
Loss on ignition	12.32
Difference	1.13
Total	100.00

Mr. Gustave Voelcker, superintendent, has analyzed all the clays around and finds them very low in free silica (quartz flour), the highest being 6 per cent. and less the further down they go, yet he says they are fairly resistent. The finely divided lime which the analyses show, he says, is not deleterious.

We have also analyses of the same clay made at the College of Mines, Houghton, for the management, given in the following letter:—

[1]See Vol. VIII, Part 1, of Report Geological Survey of Michigan. Also the Gateway, Jan., 1904. There is a brick plant at the Valley Coal Co.'s mine south of West Bay City.

Houghton, Mich., Dec. 4, 1903.

Alfred C. Lane.
State Geologist,
Lansing, Michigan.

My Dear Mr. Lane:—In reply to your favor of the 17th of November, in which you send me a copy of assay of our Mass City clay, would say that the same tallies very closely with Dr. Koenig's assay of our bottom clay. I give below copy of his assays of upper and middle and bottom belts. No. 1 being 7 to 8 feet thick; No. 2, 6 to 8 feet thick, and bottom unknown beyond 30 feet.

	1	2	3
Thick, feet	7 to 8 Top	6 to 8 Middle	30 & more Bottom
$Si\ O_2$	68.20	53.86	49.00
$Al_2\ O_3$	15.72	17.96	14.56
$Fe_2\ O_3$	4.32	5.72	4.64
CaO	2.00	5.22	10.54
MgO	1.00	2.42	3.98
$Mn_3\ O_4$	trace	trace	trace
$K_2\ O$, $Na_2\ O$	2.72	3.26	4.02
$H_2\ O$, $C\ O_2$	5.83	11.51	13.26
	100.00	100.00	100.00

Our experience shows that the combination of No. 1 and No. 2 makes a very hard brick, of uniform pink color. Very satisfactory in every way.

Respectfully yours,
(Signed) M. VAN ORDEN.

The peculiar thing about this clay as compared with others is that there is more lime and magnesium than carbon dioxide to combine with them, so that they must exist as silicates, and we may associate this with the fact that the clays lie close to the Copper Range, in the rocks of which calcium and magnesium silicates (such as laumonite, epidote, prehnite, chlorite, serpentine, labradorite olivine) are abundant. Many of these silicates are quite fusible, and it is probable that such clays would be quite fusible, especially No. 3, which would be almost a slip clay. Another plant has been talked of at Mass City as there is a large amount of clay there and also one has been proposed at Kenton.

A clay or shale encountered in a well at 40 feet near Daggett proved to be a hard white clay quite free from carbonates and highly resistent.

We have also an analysis of a surface clay from this part of the State, as follows:—

Dec. 8, 1900.

For W. S. Oberdorffer. Menominee Co., by F. S. Kedzie.

	No. 1.	No. 2.
Insol	60.96	61.42
$(Fe\ Al)_2\ O_3$	9.38	3.62
$Ca\ CO_3$	11.81	22.77
Water, organic matter and difference	18.65	12.19
	100.00	

This "clay" is really a rock flour. There is very little alumina or kaolin about it. It must be very finely ground up silica and limestone, and would not, I should imagine, be a bad material to add to sand brick or cement brick.

There is a new brick yard at Munising, the Anna River Brick Yard. But at Munising a calciferous dolomite is also used for buildings.

The following is an analysis of a shale clay of the Michigan series, taken from near Alabaster and Sherman:—

Michigan Agricultural College.
Experiment Station.
Agricultural College, Mich., June 7, 1900.

R. A. McKay,
502 Phœnix Building,
Bay City, Michigan.

Dear Sir.—Herewith please find analysis of clay specimen:—

Silica	58.95%
Aluminum oxide	14.45
Iron oxide	7.60
Calcium oxide (lime)	2.94
Magnesium oxide	.86
Sulphuric anhydride (SO_3)	1.73
Alkalies calculated as potassium oxide (K_2O)	2.54
Water of combination	7.50
Organic matter and loss	3.43
	100.00

It is a good clay. It is entirely free from calcium carbonate and is to be recommended for its content of silica and freedom from grit.

Very respectfully,
(Signed) FRANK S. KEDZIE.

The following is a Maple Rapids drift clay. See record of well in Vol. VIII, Part II, p. 197.

SiO_2	49.90	51.00
$(Al_2 Fe_2) O_3$	19.85	17.18
$Ca CO_3$	18.32	17.31
$Mg CO_3$	10.53	9.45
Total	95.60	95.54
Difference, alkalies and water	4.40	4.46
	100.00	100.00

F. S. KEDZIE.

The following is another drift clay from the Saginaw valley:—

Case School of Applied Science,
Chemical Laboratory.
Cleveland, February 5, 1900.

Mr. S. G. Higgins,
Saginaw, Michigan.

Dear Sir.—The sample brought me some time since by Mr. Dow contains:—

Silica ($Si O_2$)	41.2%
Alumina ($Al_2 O_3$)	13.4%
Iron oxide ($Fe O_3$)	5.0%
Lime (CaO)	10.4%
Magnesia (MgO)	0.5%
Sulphuric anhydride (SO_3)	0.5%

The material is more clay than marl, and would require the addition of lime or marl in order to make a Portland cement mixture. For this purpose it would be well adapted, as the sulphur and magnesia are low, and it contains little free sand.

Very truly,
A. W. SMITH.

Finally, we have a typical series of surface calcareous clays from near Detroit, good mainly for building brick, which have been analyzed in the laboratory of Prof. E. D. Campbell for Prof. W. H. Sherzer, who is studying them for his Wayne county report, and adds the following notes:—

Jacob Daniels & Bro. East of Pere Marquette and one-quarter mile south of Michigan avenue, Springwells.

No. 1. Middle of upper layer—2½ feet from surface and 2 feet from top of bed.

No. 2. Second or red layer—2½ feet from top of bed and 7 feet from surface.

No. 3. Third or blue layer—5 feet from top and 14½ feet from surface.

George H. Clippert & Bro. East of Pere Marquette and about one-half mile south of Michigan avenue.

No. 4. Upper layer—2½ feet from the surface or 2 feet from top; 4½ foot bed.

No. 5. Red or second layer—2 feet from top of bed or 7 feet from surface.

No. 6. Blue layer—5 feet from top of bed or 14 feet from surface.

L. D. Haggerty & Son. At Pere Marquette, just north of Michigan avenue, Springwells.

No. 7. Upper yellow brown layer—2 feet from surface and 1 foot from top of bed.

No. 8. Red or second layer—2 feet from top of bed or 5½ feet from surface.

No. 9. Blue layer 5 feet from top or 12½ feet from surface.

Lonyo Brick Co. About one mile east of Pere Marquette railroad and just north of Michigan avenue.

No. 10. Sample 5 feet from surface.

No. 11. Sample 2½ feet from surface.

Proctor Bros. One and one-half miles east of the P. M. R. R. and just north of Michigan avenue.

No. 12. 5 feet from surface.

No. 13. 2½ feet from surface.

M. Downey. Two miles east of P. M. R. R. and just south of Michigan avenue.

No. 14. 5 feet from surface.

No. 15. 2½ feet from surface.

At Haggerty's, Daniels' and Clipperts' there are three sharply defined beds—the upper yellowish-brown, 2 to 5 feet thick, considerably leached and not very plainly stratified. A second or "red layer"—yellow brown, but rusted and reddened—3 to 4 feet thick and very distinctly stratified.

The third is a blue layer, fine grained and not leached; beautifully stratified. It overlies till and at Clippert's may run to a depth of 40 feet judging from borings. The clay is a lake deposit, back of the Detroit moraine, and the three beds may have been formed in the Maumee, Whittlesey and Warren stages—or the various stages of Lake Warren alone.

Eastward from the railroad the red layer gives out or passes into a yellow-brown one not to be separated from upper. Deposit of clay thins out towards Detroit and disappears on moraine. Main body to the east lies to the south of Michigan avenue.

WAYNE COUNTY CLAY ANALYSES.

BY ELMER E. WARE. UNDER THE DIRECTION OF PROF. E. D. CAMPBELL.

	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.
Silica	57.18	57.55	56.16	55.86	57.58	74.77	57.75	55.53
Alumina	16.04	13.42	10.95	15.24	13.63	8.32	14.75	10.89
Ferric oxide	5.26	3.92	3.32	4.50	3.62	3.02	3.70	4.30
Calcium oxide	6.46	7.40	10.24	7.10	6.94	3.04	5.92	9.23
Magnesium oxide	4.60	5.96	4.86	5.05	4.68	2.52	4.68	5.36
Loss on ignition	10.07	11.43	13.95	12.23	11.18	5.07	9.90	12.51
Sulphuric anhydride	.01	.64	.04	.06	.65	.05	.06	.80
Sodium oxide	.....	.....	.....	.....	.....	1.85	.....	.....
Potassium oxide	.....	.....	.....	.....	.....	1.54	.....	.....
Difference	+.38	−.32	+.48	−.04	+1.72	−.18	+3.24	+1.38
Totals	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

December 31, 1903.

	No. 1.	No. 10.	No. 11.	No. 12.	No. 13.	No. 14.	No. 15.
Silica	71.32	66.19	67.06	65.75	58.42	69.50	59.46
Alumina	12.73	12.78	16.78	15.04	13.44	14.84	14.88
Ferric oxide	4.88	5.18	4.30	5.26	4.70	4.92	4.40
Calcium oxide	1.70	3.37	1.70	3.10	5.86	1.92	5.18
Magnesium oxide	2.19	3.58	2.30	3.05	4.46	2.09	5.01
Sulphuric anhydride	.13	.06	.06	.06	.04	.16	.11
Loss on ignition*	4.67	7.42	4.98	6.85	10.08	4.42	9.38
Potassium oxide	.....	.....	.87	.74	.....	.....	.....
Sodium oxide	.....	.....	2.69	2.45	.....	.....	.....
Difference	2.38	1.42	—.74	—2.80	3.00	2.15	1.58
Totals	100.00	.....	.....	103.40	.....	100.00	100.00

* Includes combined and hydroscopic water, organic matter, carbon dioxide, alkaline chlorides, etc. ELMER E. WARE.

These analyses show beautifully the leaching out of the calcium oxide and sulphur.

CEMENT CONCRETE. CEMENT BRICK.

Another industry which has rapidly developed in this State is the Portland cement industry. As we have just issued a report on this subject[1] we need only add a few notes of current interest referring also to the heading limestone.

A sample of marl has been sent by James Searing of Lyons, from the Maple river bottom to Prof. Kedzie, which runs 96 per cent. Ca CO_3.[2]

The Lakeland deposits described by us, under the head Standard Portland Cement Co., are now being developed by the National Portland Cement Co. The average depth is said to be 18 feet, and there is a good deal of peat associated.[3]

On the other hand, the Standard Portland Cement Co. is said to be testing beds near Edgewater, 12 miles north of Frankfort. The contract is said to be for $350,000, by the Robert F. Wentz Engineering Co. The plant, like the Newaygo plant, expects to use water power which the Platte will furnish.[4]

Mr. Wentz writes:—

Toronto, Ont., Feb. 29, 1904.

Mr. Alfred C. Lane,
State Geologist,
Lansing, Michigan.

Dear Sir.—I received a copy of the State reports, etc., at Detroit, and in reply beg to thank your prompt attention to this matter. I have practically read over the entire matter on my way home, and in my spare

[1] Volume VIII, part 3.
[2] Michigan Investor, 12 16 1903. See also our report, Vol. VIII, part 3, p. 311.
[3] Detroit News, 2 11 1903.
[4] They have since turned to a limestone proposition near Charlevoix.

moments at the hotel. I am pleased to say that your investigation has been very thorough and the report, especially on marl, in which I am particularly interested, is very complete, containing a large amount of very interesting and important information. I shall be pleased to send you reports and results of analysis of Michigan raw material which I have made in the past several years. This I will do as soon as I possibly can.

I have recently made very valuable improvements in the manufacture of Portland cement from marl on the wet process, almost reducing the cost of burning to that of rock or dry process. The cost of burning however, is governed by the purity of the marl to a great extent. Marl containing a considerable proportion of organic matter is much more expensive to burn,[1] requiring a much larger amount of fuel as you will know, but with a pure marl, free from organic matter, I am able to produce with my process, from 180 to 225 barrels per kiln with a fuel consumption of about 125 pounds per barrel.

Yours very truly,
(Signed) ROBT. F. WENTZ ENGINEERING CO.,
Robt. F. Wentz, President.

A number of plants referred to in Volume VIII as in erection are, like the Fenton plant of the Egyptian Portland Cement Co., now in operation. In addition we have the El Cajon Portland Cement Company (with 425 acres near Alpena), the Onaway Cement Co. (which may also be a limestone proposition), the Aetna Portland Cement Co., near Fenton, the Logan Portland Cement Co. (the same areas as the Twentieth Century Portland Cement Co., referred to in Volume VIII), and the Palatine Portland Cement Co. (to operate on the marl beds of Genesee, Livingston, and Shiawassee counties), are among the newer propositions.

Not only is the Portland cement business growing in a substantial fashion, but industries dependent upon it, such as the making of concrete block, cement brick, and hitching and fence posts.[2]

One of the earliest places to use cement brick is Durand, where there is a church built of them. Other places are:—

The Utica Cement Brick and Block Co. (plant using gravel of Geo. B. Davis pit); Jas. Pryor & Son, Houghton (plant to use the stamp sand waste from copper mining, the old Franklin mine); F. P. Bradley, Hudson, Mich.; Ypsilanti Cement Block Co. (using Jollifer gravel pit near Plymouth, Wayne Co., i. e., an old lake gravel); Mason Tile and Cement Co., of Detroit (make cement brick and have tried some for paving), Dowagiac.

The Portland cement is always the more expensive material and should be used in quantities sufficient to fill the voids. Now even grained material has more voids, even though individual grains are very small, than gravel or sand of uneven grain, where the small grains can pack in between the large ones. Therefore in concrete it is necessary to mix gravel with sand enough to fill the voids, and then finally cement enough to fill the finer remaining voids. The theoretical maximum porosity is .4764 of the whole volume empty or about half and half. In an even grained sand, minimum porosity is 26 per cent. of the whole volume. An average clean

[1]These are commonly bluer or clay colored rather than white. L.
[2]Lansing Cement Post Co., American Cement Post Co., of Marshall. Hillsdale Fence Post Co., Geo. F. Demorest, Lapeer, and Pulfrey & Pond, St. Johns, hollow cement blocks.

beach sand will run about 40 per cent. voids, so that a cubic foot, which if it were solid quartz, would weigh about 2650 ounces (1000 ounces of water to the cubic foot), will weigh but 1590 ounces, or 100 pounds. The average specific gravity of Michigan sands and gravels according to my test is not far from 2.65. Thus if we take the number of ounces of water a cubic foot of a given sample of sand or gravel will absorb, and divide by 1000 we shall get the proportion of the volume which is pore space. Or, if we take the weight of a cubic foot in pounds and multiply by 0.6, or, more exactly, find the weight in ounces and divide by ten times the specific weight (say 2.65) we shall get the per cent. which is not pore space.

The per cent. of cement by volume required, therefore, will vary with the porosity of the sand. Two or three parts of sand to one part of cement is about all that it is wise to add. Any further dilution of the cement should be by coarser material. A common proportion may be 1 cubic yard broken stone or gravel, with one-half volume voids, requiring one-half yard of sand, which will have one-third its bulk voids, requiring so much or one-sixth cubic yard of cement, i. e., the proportion of gravel, sand or cement for one cubic yard of concrete will be 1 cubic yard gravel, one-half cubic yard sand, one-sixth cubic yard cement, and about the same proportions (a little less cement) by weight.

I do not think that pure sands will be so economical of cement as less assorted sands, beach and river sands and shingle, and as I have said, the kame and overwash gravels and eskers of the glacial epoch.

I understand that beside at Durand, concrete block plants are planned near Rochester, St. Charles, Lansing, Ypsilanti, etc.

The economic geologist is more especially concerned with the other raw material, the sand or the gravel. This should of course, be convenient to transportation and free from clay, mud or slimy material. But that does not mean that it must be very even gravel. Quite the contrary. "The best sand is that of very uneven sizes and sharp." The more uneven the sizes the smaller are the voids and the heavier the sand.

But here in Michigan the glacial gravels are often unassorted, so that little or no sand needs to be added[1] and in any case of material for any extensive proposition, one should have the amount of pore space tested.

SAND BRICK.

Another important industry in development is that of making sand brick. Among the most important papers are those of S. V. Peppel, formerly of the Ohio Geological Survey, now of "Rock Products," Louisville, Ky. I am also indebted to Prof. O. P. Hood for suggestions, and to Mr. W. O. Kutsche.

A sand brick is a mass of sand or fine gravel (under 1-20 inch) cemented by a net work of silicates of lime with or without magnesia or other earths made by steaming under pressure, a mixture of sand or gravel with slacked lime.

The sand, as for concrete, should be of varying size, which may be provided by crushing some of it. "If we had a sand with a good assortment of sizes from coarse to fine, we ought to have sand finer than 150 mesh equal in amount to the weight of lime to be added." Clay is deleterious, but, if not over 10 per cent., may be counteracted largely by using

[1] See article by Geo. S. Pierson, Michigan Engineer, 1904.

more lime. It adds ease of working and the sand should not be quicksand, but mold well. To the sand 5 per cent. to 10 per cent. of slacked lime are added. A molding pressure of best about 15,000 pounds per square inch is used, and they are then exposed to steam at a pressure of 120 to 150 pounds, and temperature of 180° C. to 185° C., for say 8 to 10 hours. Mr. Peppel found that freezing actually improved the brick materially.

The absorption is said to be 8 to 10 per cent. of the weight of the dry brick. One Michigan specimen which I tested ran as high as 12 per cent. The crushing strength is better than that of the best sandstone if properly made, but a heavy pressure of 200 to 250 tons per brick is important to get the best results, and a uniform pressure is not always attained.

In regard to merits of different systems of manufacture, that is a matter for the mechanical engineer, and we would refer to the gentlemen whom I have mentioned above. Great advantages of all methods are, however, rapidity of production and economy of fuel.

Among the sand lime brick plants in operation or construction in the State are as follows:—

The Holland Brick Co., working under the patents of H. E. Brown of Coldwater, and making dolomitic sandstone brick, W. O. Kutsche, superintendent. They are working on sand at their plant corner of Fairbank avenue and Eleventh street, at Holland. The Jackson Pressed Brick Co. and the Battle Creek Dolomitic Brick Co., are also to use this process. This means that they use a slacked lime made of magnesian limestone. Most of the Monroe county lime (except the Christiancy quarries) is of this character. The quarries in the Niagara limestone along the west shore of Lake Michigan, as the Manistique, are pretty sure to be dolomitic lime. The Petoskey, Alpena, Bay Port, Sibley and Bellevue limestone is ordinarily not a dolomite, though layers may be found at Petoskey and Alpena which would yield it. There would be an advantage in combining this process with the making of cement, in that the dolomite lime is just the kind which is not wanted for cement. There is probably no especial advantages in quality in using magnesian lime. Peppel thinks the contrary.

The American Sandstone Brick Machinery Company has a plant at the south end of West Saginaw, near the glass works, well spoken of by Peppel, using a sand connected with the old Lake Algonquin beach line. The sand lies in a ridge running north of N. W. and cut by the M. C. R. R. It is at least 10 to 15 feet deep, with no apparent stratification. It is probably a wind or dune deposit between the Tittabawassee river inlet and the great lake of the time, on a projecting spit, and rain percolation since has destroyed what little stratification there was. It is *not* a quicksand, but molds well and has a little organic matter. This and a Muskegon plant are on the system of F. Komnick of Germany. Another plant is talked of for West Bay City. Peppel gives a description of the process.

Finally, we have the plants using Huennekes system. The parent company of the State is the Michigan Sand-Lime Brick Co., of Saginaw. They have a plant in operation using Saginaw river sand at the north end of the city near Saginaw, and as they have the rights for Michigan, are interested in plants in the copper country, Middleville, Detroit, and the Sault.

"C. W. Boyle and Geo. O. Cole, of 76th North Market street, Grand Rapids, Michigan, are taking preparatory steps for the organizing of a

brick manufacturing plant. Mr. Boyle is the inventor of a new machine for manufacturing sand or chemical brick, on which he obtained a patent from the government, July 31, 1903. The new brick after leaving the machine is so soft that it cannot be handled, but after being subjected to a chemical treatment become harder and more durable, it is claimed, than any variety of brick now used for building purposes, and the brick can be manufactured and put on the market in 48 hours. One residence in this city has been built of this brick, which has proved satisfactory."

Mr. Peppel[1] remarks: "If the last five systems described, were all to work under parallel conditions, I do not believe that the cost of production would vary more than 35 cents per thousand." * * * "The cost of production in this country, independent of depreciation and interest on investment varies from $2.40 to $4.00 per thousand. The selling price ranges in different localities from $8.00 to $15.00 per thousand." * * * "I see no reason why plants should not be made independent of all the above mentioned patents or systems." * * * "There is no patent process of hardening with steam under pressure, since Dr. Michaelis of Germany allowed his patent to expire some years ago." * * * "We are not advocating sand lime brick for pavers." * * * "Those locations should be first selected where sand is abundant and fuel inexpensive.

The last remark seems to indicate Lake Superior as an appropriate region, and it is to be noted that freezing and thawing seems to strengthen them. But in general, Michigan is well supplied with sand, and while we have coal and peat, fuel is not and never will be as cheap as farther south, for there is more demand and less supply.

[1] S. V. Peppel, Louisville, Ky. Further contributions to the manufacturers of artificial sandstone and sand brick, p. 43.

TRANSMISSION OF HEAT INTO THE EARTH.

In several lines of investigation the question of conductivity or diffusivity of substances has come up as an important geological factor. Peat moss is a good non-conductor, and this lends it part of its practical value in growing nursery stock. Moreover it cannot be without influence upon peat bog vegetation that in the very heat of summer their roots are immersed in cold water while their leaves are exposed to the fierce heat of the summer sun. Again the heat diffusivity of the soil seems to indicate its porosity.[1]

From the temperatures of flowing wells we can draw some conclusions as to the depth from which their water is drawn, and in the same way we can infer from the temperature of springs the depth of their source. Mr. Frank Leverett has made practical use of this in studying the Ann Arbor water supply.

Finally in studying the temperatures at great depths and the rate of increase in mines we need to know the surface temperature from which the increase of temperature in going down begins, and in all these cases we find involved the fact that the temperature of the ground varies, being perceptibly affected for two or three feet by the daily range of temperature and for about twenty times greater range of depth, by the change from summer to winter. I found a large series of observations on soil temperatures by Prof. R. C. Kedzie which had never been completed, and I spent quite a while in finding a method of treating the subject which should be sufficiently accurate for the geological purpose and for the observations and yet not too technical.

We may treat the variation of temperature for a day and its spread down into the earth very nearly as though it were the only variation and suppose each day the top of the mercury of the thermometer rose and fell as a ship would rise and fall while a wave passed under it. If that is so and the period of variation is a day, the average of two observations half a day apart will give the average mean temperature of the day. If we subtract this mean temperature from observations of the temperature one-quarter of a day apart then the square root of the sum of the squares of the difference of two successive observations six hours apart will be the greatest difference for the day. We find this difference decreasing as we place our thermometer deeper in the earth, and the less the diffusivity of the soil for heat and the greater its porosity the less will the daily or annual differences of temperature be at a given depth. Moreover the quotient of the differences is proportional to the

[1] See pages 24 to 25 of this report.

exact time when this greatest difference from the mean occurs, and again we find, this time is greater the deeper in the earth the thermometer is and the less the diffusivity of the ground.

The mathematical treatment below gives us the exact method of computation.

We may pick out from it certain facts of general interest. The range of surface soil temperature is greater than that of the air temperature. In a soil like that at Grayling or Lansing with the usual summer amount of moisture, etc., it takes about a day for the heat to penetrate two feet and the range at that depth is only about 5% of that at the surface. The annual variation would penetrate in a year about $\sqrt{365}=19$ times as deep or say 38 feet, and at 19 feet it would be coldest in summer. The range of variation of temperature at 38 feet would again be only about 5% of the range from the mean daily temperature the last of July to that the last of January. These figures vary of course according to the diffusivity.

Mathematical Treatment.

The variations of temperature at the surface of the soil may be taken as the result of a combination of a number of different variations of temperatures. These latter will differ in amplitude, that is to say, in range of temperature due to them. They will also differ in period, that is, the time which elapses between the occurrence of the greatest divergence, and the recurrence of the same, that is, between successive maxima. Two of the most prominent periods are the day and the year. They will also differ in the date at which the first maximum takes place, after any date that we take from which to begin to reckon our time, say midnight of January 1. It may be shown by Fourier's theorem that no matter how complicated the variation of temperature, it may be considered as the sum of a series of such harmonic variations,[1] each being expressed mathematically as—

$$(1)\ T=c\ \cos\left(2\pi\frac{t}{p}-l\right)$$

In this expression—

T is the divergence of temperature from the average, eliminating this particular variation, at a time t.

c is the amplitude, that is, the maximum divergence from the average.

p is the period for the particular term, the length of time between maxima.

π is 3.1416, but in estimating angles $2\pi=360°$, so that $2\pi\frac{t}{p}$ is an angle which is to four right angles as the time t for which T is sought is to the time between maxima.

l is the value $2\pi\frac{t}{p}$ assumes at the time of the first maximum, and the time of it after the date of the beginning is $l.\frac{p}{2\pi}$

[1] Byerly, Fourier's Series, Chapter II.

Now, at a depth, which we will call x, the temperature, so far as it is due to the surface temperature, may be represented as the sum of a set of vibrations having the same periods, but the maxima will be less and later.[1] Each will be expressed mathematically as—

$$(2)\ T_x = c\ e^{-R} \cos\left(2\pi\frac{t}{p} - l - R\right)$$

In this expression—

T_x is the temperature of a point at the depth x at the time t as before.

c, π, p, t and l have the same meanings and values as in expression (1).

e is the exponential base 2.71828.

R depends on the retardation of the maxima which depends on the depth, the period, and the capacity of the ground to diffuse heat. This latter we will call K.

K is by Byerly called a^2 and by Kelvin $\frac{k}{c}$. It is proportional to the rate of change of temperature with the time at a given depth. It is also inversely proportional to the acceleration of the change of temperature for different depths at the same time; i. e., $D_t u = KD_x^2 u$. K is usually assumed to be invariable, though this is not strictly true, and in such case if the temperature was proportional to the depth, it could not change with the time.

It may be shown that—

$$(3)\ R = x\sqrt{\frac{D_x^2 u}{D_t u}}\ \frac{\pi}{p} = x\ \sqrt{\frac{\pi}{Kp}}$$

As to the units, x and $\sqrt{dx^2}$ are referred to the same unit, also dt and p, du and d^2u, and consequently a change in units does not affect R, nor does a change in temperature unit from degrees Fahrenheit to degrees Centigrade affect K. K is the conductivity and c the thermal capacity per unit volume, which is for water, 1; for most rock, about .5; and for air, .000307.

Obviously the diffusivity, or spread of heat, when the strata have to be heated up as the heat wave spreads, will be relatively less than when the conductivity or flow has become steady, if the body absorbs a good deal of heat in being heated up. One must be careful not to confuse the conductivity and the diffusivity, as is often done; and in part I myself, in my Annual for 1901, page 247, have mixed some conductivity and diffusivity data, as writers are sometimes obscure. The conductivity may be defined, for instance, as the number of calories, or heat units, which an indefinite slab, without varying the temperature, will transmit per square centimeter through a slab a centimeter thick, the difference of temperature of the two sides being 1°, while the diffusivity is the conductivity divided by the thermal capacity per unit volume. This is the specific heat per unit weight multiplied by the specific gravity. The former is calculable from the chemical composition, and is for most rock-forming minerals not far from .20. For water, it is

[1] See Byerly's Fourier's Series, Art. 60, much simplified here.

1.00. The specific gravity for rock-forming minerals is usually between 2.5 and 3.5, consequently the specific heat capacity per unit volume of the strata, except for porosity, is near .5 to .6. If the pores are filled with air, the heat capacity per unit volume is diminished; if filled with water, it is increased and the diffusivity diminished relative to the conductivity. Unless convection currents of water come in, therefore, a wet soil will propagate temperature changes less than a dry one. It may propagate heat from below more rapidly, but heat from above less rapidly.

To get the greatest values of the temperature T_x we shall have in eq. 2 $\cos\left(2\pi\frac{t}{p}-1-R\right)=1$, the greatest value a cosine can have, and then $1+R=2\pi\frac{t}{p}+2n\pi$, the *first* maximum (when $n=o$) being at the date $\frac{1p}{2\pi}$ at the surface, and at the date $\frac{(1+R)\,p}{2\pi}$ for the depth x. The difference $\frac{Rp}{2\pi}$ is the time it takes the heat to penetrate the distanee x, which is from equation (3)—

$$(4)\quad \frac{x}{2}\sqrt{\frac{p}{K\pi}}=\frac{Rp}{2\pi}$$

Variations of long period move in more slowly than those of short period, but they are appreciable at a greater depth. For when we come to consider the amplitude or range of variation in temperature, it is the original amplitude multiplied by e^{-R}, i. e. $(0.36788)^R$, which is always a fraction decreasing from 1 as R increases from 0, and thus decreases with the depth also, but more slowly the better the diffusivity and the longer the period of variation.

The diffusivity (K) in materials such as those of which the earth's crust is composed, usually varies from .001 to .01,[1] if the unit of time is a second, and of distance a centimeter.

In the progress of fluctuations of temperature from the surface they soon tend to smooth out minor irregularities as they go down, and if not strictly harmonic, become more nearly so. Now for any one particular set of heat waves, say those due to day and night, as they go down—

(1) The times of maxima are retarded by an amount which is to the period (p) of the heat wave (in the instance cited 1 day) as R is to 2π, where—

$$2\pi=\frac{66}{7}\quad\text{and}\quad R=x\sqrt{\frac{\pi}{Kp}}$$

(2) The amplitude of vibration is to the original amplitude as $1:e^{-R}$; i. e., is $(.36788)^R$ of the original. We can for any one fluctuation take $p=1$ if we choose a proper value of K.

[1] Annual Report 1901, page 247. B. O. Peirce. Rocks like traps have a diffusivity of about .006 to .007. That of the Calumet conglomerates is as high as .01, which is taken as a rough average of underground strata by Lord Kelvin.

Table of Diffusivity.

K for different units of depth (x) and time (p).

	Second.	Hour.	Day.	Week (7 days).	Month (1-12 year).	Year.
Centimeter	1 (a)	3600	86400	610800	262800	31536000
Meter	.000001	.0036	.0864	.6108	.2628	31536
Inch	.154	556	13700	93600	40600	4870000
Foot	.001073	3.87	92.8	684	2830 (b)	33800 (c)

(a) Units of B. O. Peirce, Callendar, and McLeod.
(b) Units of Angstrom.
(c) Units of Kelvin.

Suppose, for instance, we ask to what distance from the surface does the variation amount to one per cent of that at the surface? Then

Amplitude $= c\,(0.36738)^R = .01c$

Canceling and taking logarithms.

$R\,(-.4343) = -2$ Therefore $R = 4.6 = x\sqrt{\pi/Kp}$

Suppose the variation is daily, if we let $p = 1$, and the diffusivity is (.01, in centimeters and seconds i. e.) .928 in foot day units then x is about 2.3 feet. The soil diffusivity will be usually from 2/3 to 1/5 of this, and since the daily variation of the surface soil temperature is not over 30° to 40°, the daily variation is usually less than a degree Fahrenheit, even at less than 2/3 foot below the surface.

It is plain, however, that when we come to consider thawing frozen ground, or vice versa, an enormous amount of heat will be absorbed in thawing the same out. The diffusivity may be easily ten times less. On the other hand, a warm rain may carry the temperature down very rapidly.

For instance, I made the following temperature observations on the peat bog of Mud Lake, Sec. 1, T. 1 S., R. 5 E., in Washtenaw County, July 16, 1903:—

	Fahrenheit.
Temperature of air in shade	86°
Temperature of air in sun, surface of bog	117°
Temperature at ¼ inch depth	94°
Temperature at 2 inches	73°
Temperature at 4 inches	63° or 62°
Temperature at 12 inches	57° to 56.4°
Temperature at 18 inches	57°

At other places in that same bog the some day, we found at different times: In sedge marsh at 3 inches depth, 64°; at 4 inches depth, 50 feet within shade of Tamarack belt, 64° F.; in Cassandra belt, 3 inches below water level, 56°, and at 8 inches, 56½°; 2 feet deep in peat, 56.3°; away out on the floating bog, at 4 inches depth, 68°; at 18 inches, 66°. Now the maximum temperatures that day for adjacent stations of the weather service were 80° to 82°, and the minimum the previous night were from 46° to 55°.

July (1903)	14	15	16	17	Ave. July	Ave. Aug.
Ann Arbor	72 —52	74—45	79 —51	81—57	82.5—60.2	76 0—56.2
Ypsilanti	71 —50	72—44	76 —55	81—58	80.5—58.2	85.0—54.9
Average	71½—51	73—44½	77½—53	81—57½	81.5—59.2	76 5—55 5
Average for day	61	59¼	65	69	70.4	65½

The range of soil temperature for the day could hardly have been over (117–65) $52 \times 2 = 104°$. The amplitude at 1 foot and 1.5 foot would then be at a diffusivity K = .928 for units of a foot and day 15.9° F. and 6.35° F. respectively and the maximum or the minimum would be reached 29/100 of a day and 44/100 of a day later respectively, than on the surface, and a greater range means a greater diffusivity. To get a temperature of almost 10° below the daily mean at a foot, as we have, we should have to assume a lower minimum soil temperature than is probable, aud greater diffusivity than is really likely. Finally, the possibility of the temperatures at a foot and a foot and a half diverging from the daily mean 10° on account of the cold the night before, utterly breaks down, in view of the relative constancy of the temperatures both in depth and at various times of day.

We must then take the other alternative that the temperatures are practically unaffected at a foot's depth by the daily variation, the amplitude of which at that depth is reduced to not over 2°, and then the diffusivity (c.g.s.) will be not over .004 to .005. From considering the temperature at 1 foot as fixed by the annual variation in temperature we find that the greatest summer temperature at a foot depth would be nearly thirty-seven days later than at the surface[1]. This leads to an extremely low diffusivity, like that of pumice or dry sand, and shows what a good nonconductor peat may be taken to be. The result may, however, be affected by evaporation and consequent depression of temperature, the peat acting like the wet flannel wrapper of a Hindoo water bottle.

Suppose we have observations at intervals of one-fourth of the period of variation in temperature apart, i. e., in the case of the daily variation six hour intervals, we have, calling them

---

[1] R (−.4343) = log. 2- 104 or log. 2·24, according to the amplitude of the surface variation taken = −1.716 + or − 1.079 +.

$\therefore$ R = 3.96 or 2.48 + $\therefore$ if x = 1 and p = 1. From eq. (3).

$K = \frac{\pi}{R^2+} = 0.2$, or 0.5 in day foot units = .002 or .0056 c.g.s.

Supposing that the temperature at 1 to 1¼ foot depth 56.6° is fixed by the annual variation (it is probably 2° or 3° too low on account of previous cold days), which is, or should be, just about a maximum (70°.6 daily mean) at the surface on July 17; reckoning the time from that same date last summer (l = 0), taking this time p = unity = 1 year (the diffusivity will accordingly be referred to years and feet), we have—

$$T_x = (56°.6 - 46°.6) = 10° + = (c = 24° = 70.6 - 46.6)\, e^{-R} (\cos 2\pi \frac{t}{p} - l - R)$$

$$= 24 \cos (2\pi - R)\, e^{-R} = 24 \cos R/e^{R}$$

$= \log 24 + \log \cos R - R$ (log e = .4343) = − 38. This equation is nearly satisfied if $R = (\frac{1}{360}) 2\pi = .646$ in foot year units. $\frac{1}{360} \times \frac{365}{} = 37$ days, which is the difference between the time of greatest heat at the depth of 101½ feet at which 56° 6 is taken and at the surface. The maximum mean daily temperature at a foot depth is over a month later than at the surface. And if $R = .646 = x \sqrt{\frac{\pi}{Kp}}$

$\therefore K = \frac{\pi}{R^2} = 7.6$ in year foot units = .0002 in c. g. s.

$T_1 + M, T_2 + M, T_3 + M, T_4 + M$, M being the average temperature.

$$T_1 = c\, e^{-R} \cos (2\pi \frac{t}{p} - l - R)$$

$$T_2 = c\, e^{-R} \left[\cos (2\pi \left(\frac{t}{p} + 1/4\, p\right) - l - R) = \sin (2\pi \frac{t}{p} - l - R)\right]$$

$$T_3 = c\, e^{-R} \left[\cos (2\pi \left(\frac{t}{p} + 2/4\, p\right) - l - R) = -\cos (2\frac{t}{p} - l - R)\right]$$

$$T_4 = c\, e^{-R} \left[\cos (2\pi \left(\frac{t}{p} + 3/4\, p\right) - l - R) = \sin\ 2\ \pi\ \frac{t}{p} - l - R\right]$$

The sum of two observations a half period apart $T_1 + M$ and $T_3 + M$ or $T_2 + M$ and $T_4 + M$ will give us twice the mean average temperature. Then we can get T_1, T_2, etc., readily. Squaring the sums, we get—

$T^2_1 + T^2_2 = c^2 e^{-2R} (\cos^2 + \sin^2 = 1) =$ the square $(c\, e^{-R})^2$ of the amplitude at the depth x, from which we can readily find R, if we know c. Or, if we have a series of different observations at different depths, we can eliminate c between them. Also dividing—

$\frac{T_2}{T_1} = \tan (2\pi \frac{t}{p} - l - R)$, from which we can also compute R.

There are thus two ways of computing the diffusivity of heat. In the former case we estimate from the decrease in amplitude or amount of maximum variation and that is all we need to know. But if we have a series of timed observations, we can also eliminate the diffusivity from the time at which this maximum temperature occurs for various depths.

To illustrate these principles and get some idea of the diffusivity near the surface we may proceed as follows:

Between 1888 and 1892, measurements of the soil temperatures at different depths were made at Grayling and at Lansing.[1]

These were read three times a day, at 7 a m , 1 p. m., and 7 p. m., i. e , six hour intervals, but not in the winter. Therefore they do not help us as regards the blanketing effect of the snow in winter, and a study of the annual variation must be very imperfect. We can, however, get some comparative results as to daily variation and as to diffusivity, and apply the formula above; and it is well to notice also that the composition and porosity of the Grayling soil has been tested, as well as its diffusivity.[2]

The addition of morning and evening observations should give us twice the daily mean, free from the daily variation.

Also $$\frac{T_{7\,A.M.}}{T_{1\,P.M.}} = \frac{T_{7\,P.M.}}{T_{1\,P.M.}} = \tan \sqrt{1 + R}.$$

From this we derive $1 + r$, which is proportional to the time after 1 P. M. that the daily maximum arrives. Finding this for various depths, and remembering that $R = x \sqrt{\frac{\pi}{K}}$ and that we know the depths, and the

[1] Report State Board of Agriculture, 1888, pages 154-164; 1889, pages 85-101; 1890, pages 143-152; and 1891, pages 92-97.

[2] Bulletin State Board of Agriculture, Bull. 99, p. 11, also this report above. pp. 15, 16.

period (p) is taken as 1, we shall have expressions with only l and K, so that if we have these observations for two different depths we can find both l and K.

Lansing.

Taking for instance, the observation for September, 1891, at the Agricultural College, we have:—

Depth.	7 A. M.	1 P. M.	7 P. M.	7 A. M. + 7 P. M.	Mean.
3 in.	61.3	72.3	69.2	130.5	65.25
6 in.	63.6	67.2	68.1	131.7	65.85
9 in.	64.8	63.8	66.5	131.3	65.65
12 in.	65.1	65.1	65.7	130.8	65.4
24 in.	64.3	64.4	64.3	128.6	64.3
Average.....					65.29

If there were only daily harmonic variations to account for, the column of means should be identical. The variation in the means is due to sine terms of a period longer or shorter than a day. Throughout we assume that we can isolate pure harmonic vibrations corresponding to the single curve. This is not strictly true, but the farther from the surface the more the curves tend to become such. With the exception of the 24-inch thermometer, which is distinctly lagging in temperature, owing to the annual variation, the variation is less than $\frac{1}{4}°$.

We have, accordingly, as variations from the means for the various depths:—

Depth inches	T_7	T_1	T_7	$\frac{T\ 7\ P.\ M.}{T\ 1\ P.\ M.}$	$l + R$ in degrees $15° = 1$ hr.	$l+R$	$\frac{l+R}{x}$	K in inch and day units	K in cgs. units	ce^{-R}
3	−3.95	7.05	3.95	.561	29° 20′	.51	.17	105	.0083	8.1
6	−2.25	1.35	2.25	1.65	58° 40′	1.02	.17	105	.0083	2.6
9	− .85	−1.85	.85	− .458	155° 20′	2.72	.30	35	.00275	2.0
12	− .3	− .3	.3	−1.	135°	2.55	.20	78.5	.0062	1.42
					360° or	6.28	.26			
24	− .0	+1.1	+ .0	−0.	180°	+3.14	+.23	46	.0036	1.1

From the two shallowest depths we infer that the hottest part of the day at the surface was almost exactly 1 P. M. and $l = 0$. The diffusivity[1] will vary between .003 and .008. Apparently it takes about four hours for the daily heat wave to penetrate half a foot, but nearly twenty-four hours for it to penetrate two feet.

Grayling.

Let us now apply this same analysis to July, 1888, at Grayling:—

Depth.	7 A. M.	1 P. M.	7 P. M.	7 A. M. + 7 P. M.	Mean.
3 in.	63.92	75.49	75.52	139.44	69.72
6 in.	66.52	71.10	74.06	140.58	70.29
9 in.	68.28	68.97	71.79	140.07	70.02
12 in.	68.26	68.02	69.74	138.00	69.00
24 in.	66.80	66.77	66.60	133.40	66.70

[1]The lower diffusivity may be due to the greater dampness of the lower layers.

The variations in the means shows the importance in influence of periods with others terms than 1 day. In the first three depths the difference is not over ¼°. Obtaining T we have:—

x	T_x (7 A. M.	T_x (1 P. M.	T_x (7 P. M.	$T_7 + T_1$	$(1+R)\frac{360}{2\pi}$	1 + R	Time that maximum is retarded.
3 in.	−5.80	+5.78	+5.80	+1.003	45°	.79	3h.2
6 in.	−3.77	+0.81	+3.77	+4.65	77°	1.35	5h.4
9 in.	−1.74	−1.05	+1.77	−1.69	90 + 31°	2.12	8h.1
12 in.	−0.74	−0.98	+0.74	−0.75	180° −37°	2.49	9h.55
24 in.	+0.10	+0.07	−0.10	−1.43	360 −55°	5.31	20h.04

We obtain, using the values at three inches and six inches to determine l, l =2 (.79) — 1.35 = .23, indicating that the warmest part of the day at the surface was nearly an hour after 1 P. M. The values for R will be: .57, 1.12, 1.89, 2.26, and 5.08 respectively; and of R/x = $\sqrt{\frac{\pi}{Kp}}$ .19, .19, .21, .19, and .21 respectively, a fairly uniform rate averaging .020 in inch-day units, which will lead to a diffusivity of 78.5 in inch-day units, or .006 in c.g.s.

For amplitudes we find, for the $\sqrt[2]{T_{x7}^2 + T_{1x}^2}$ successively, 8.17°, 3.36°, 2.30°, 1.23°, and 0.71° respectively. If we assume the maximum divergence from the average at the surface is 15°, we shall obtain for values of R: .61, 1.33, 1.88, 2.50, and 3.06, and for R/x .20, 0.22, 0.21, and 0.14, which agree quite fairly (except the last, where the amplitude at two feet is so slight as to be greatly affected by the error of observation, and may be affected by the yearly variations.)

Thus we may conclude that the mean diffusivity at the point where the observations were made at Grayling was on that July close to .006, the average surface temperature between 69° and 70°, while the daily range of the soil temperature was 14.6 above and below; i. e., from 56° F. to 84° F.

We have also tried one other month, April, 1889. The results were as follows: The mean range of temperature at three inches was greater than that of the air, so the surface range of soil temperature may have been much greater. The whole variation was not nearly so great as in July. By taking the differences from the mean value of the temperature at any two times six hours apart, and squaring them, we obtain the square of the greatest difference at that depth as before, and accordingly find at 3, 6, 9, 12, and 24 inches respectively, maxima of 8.1, 2.62, 2.03, 1.34, and 1.21 respectively. From these again the diffusivity may be computed. If we assume R = 51 for three inches, we find a maximum at the surface of 13.3 above the mean, the mean daily variation being about 27°, which harmonizes well with atmospheric data, and we find for successive values of the retarding factor, R, values of 1.62, 1.9, 2.3, 2.5, respectively. Then R/x will be .17, .27, .21, .20, .11, respectively, or an average of .18, or for the diffusivity in units per day, .98, or in c.g.s. units, .007. The average diffusivity computed from the retardations of the maximum was .006.

We see, then, that records of the temperature at different depths give us check methods of determining the diffusivity and that only three observations a day, at intervals of six hours, will help us out pretty well. And after we have the diffusivity determined, we can readily figure the amplitude of a heat or cold wave at a given depth, and how long it will take to get down there.

It is scientifically desirable that the observations taken with so much care by Prof. R. C. Kedzie be worked up completely to obtain the different diffusivities of the soil. Important light on soil physics would probably be obtained. The direct geological bearing is not great enough to warrant my undertaking the work. The results above give us an idea of the diffusivity.

The above treatment must not be taken as a thorough and accurate treatment. Byerly, above cited, gives the necessary mathematical foundation, and I also have the following papers which work out especial cases in detail.

Louis Saalschütz: Astronomischen Nachrichten, Altona, 1861, "Ueber die Warmeveränderungen in den höheren Erdschichten unter dem Einplüsse des nicht periodischen Temperatur wechsels an der Oberfläche."

Angstrom: Nova Acta regiae Societatis Upsaliensis, pp. 147-224, series III, Vol. I, 1855—"Température de la terre." The same pp. 50-72, Vol. III, 1861, "Conductibilité des corps."

B. O. Pierce: Proceedings of the American Academy of Sciences, August, 1898, October, 1899, June, 1900, May, 1903, a series of papers.

Callendar aud McLeod: Transactions of the Royal Academy of Canada, 1895-1896, a series of papers on soil temperature observations.

GRAIN OF ROCK.

In connection with the Isle Royale report[1] already referred to I developed a theory that the coarseness of grain in igneous rocks was not only somewhat dependent on the rapidity of cooling, but sometimes depended on it in so definite a way as to be capable of mathematical expression. I found that if a mineral was formed in a time $T_1 - T_2$ during a drop in temperature $U_1 - U_2$, then the area of a cross section of an average grain was proportional to the time and inversely proportional to the drop, or dependent on $\frac{T_1 - T_2}{U_1 - U_2}$.

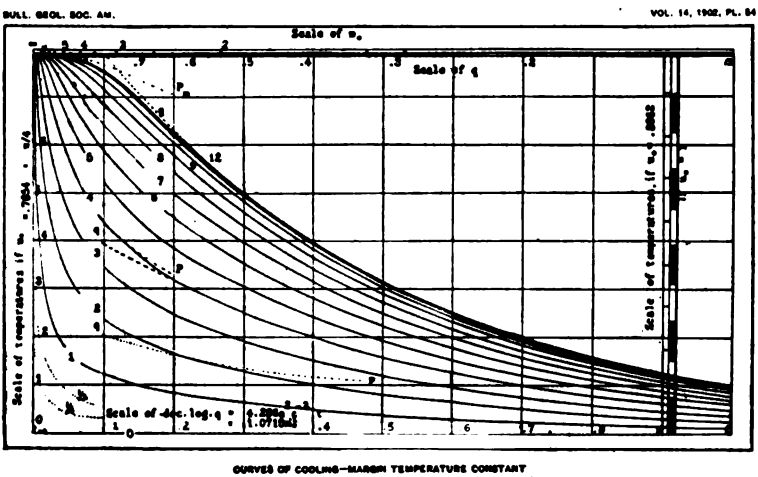
BULL. GEOL. SOC. AM.
VOL. 14, 1902, PL. 84
Scale of u_o
Scale of q
Scale of temperatures if u_o = .7854 = c/a
Scale of temperatures, if u_o = .8862
Scale of dec. log. q =
CURVES OF COOLING—MARGIN TEMPERATURE CONSTANT

FIG. 1. This shows the cooling of an igneous sheet, the margins of which are kept at a constant temperature, taken as 0° and represented by the bottom line of the diagram. The temperatures are represented by ordinates, and three different scales of temperature are given, corresponding to different values of the initial temperature. The main scale at the left is the same as used in the Isle Royale report. To the right is the scale if, as is assumed by Queneau, $u_o = .8862$, and also if the initial temperature of the igneous sheet (that is, its excess of temperature over the surrounding rock) is taken at 1. The abscissas to the right represent the lapse of time, the main scale at the bottom being proportional to dec. log. q and t, and the scales above being proportional to m_o and q, which are defined in the text. Curves for twelve points from the center to the margin are drawn in full lines, and in dotted lines two curves still closer to the margin, one twenty-fourth and one forty-eighth of the distance to the center respectively. Also for curves 12, 4, and 2 we indicate by dashes the points where the curves of the approximate solutions which we have used in practice leave the curve which we have taken them to represent, to show how small the error is which we make in using them.

[1] Vol VI, Part I. This subject has been worked on independently by Tammann and Doelter. I have not seen all the original papers, only the summaries given in Neues Jahrbuch. 1903, 1, and Central Blatt, 1903, p. 608. The *power of crystallization* is defined as the number of crystal granules forming in a unit volume in a unit of time. The velocity of crystallization is the linear velocity of growth in millimeters per minute. It seems to depend upon the number of degrees below the temperature of saturation, respectively fusion, at which the crystallization takes place and apparently attains a maximum some 15° below and more, according to Doelter's ideas, 20° to 25° below the fusion point for augite and plagioclase, nearer the temperature of solidification than of fusion.

Pressure does not make much difference except as it may retain H_2O, etc., but the crystallization is very sensitive to addition even of chemically neutral substances.

Glass formation may be due either to slow velocity of crystallization or weak power of crystallization.

During the first few degrees below saturation temperature, microlites and elongate forms tend to occur, later come the more equal sized grains. In augite the length of the grains formed in 100 minutes is not ten times that formed in ten minutes, but Doelter's cylinder, which cooled in 100 minutes, had a slow cooling margin and a more rapidly cooling center, a case we shall refer to later.

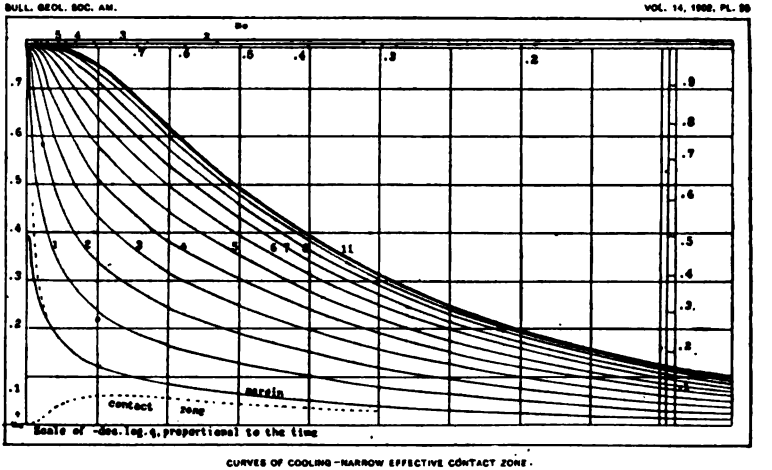
BULL. GEOL. SOC. AM.
VOL. 14, 1902, PL. 26
Bo
Contact zone
Margin
Scale of -dec. log. q, proportional to the time
CURVES OF COOLING-NARROW EFFECTIVE CONTACT ZONE.

FIG. 2. Illustrating cooling, as in Fig. 1, where there is a narrow effective contact zone, one-twelfth the width of the dike. The dotted line shows the rise and fall of temperature in the middle of the contact zone. There is also shown by dashes the point where curve 2 of Fig. 1 diverges from the curve of marginal temperature.

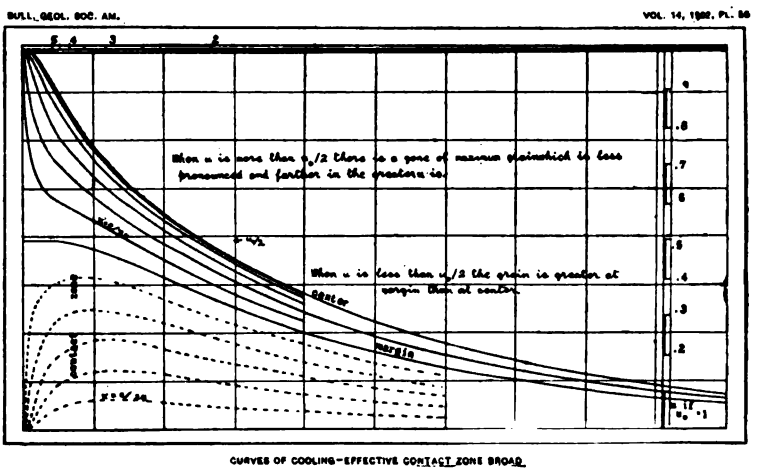
BULL. GEOL. SOC. AM.
VOL. 14, 1902, PL. 26
When u is more than u/2 there is a zone of maximum grain which is less pronounced and farther in the direction of
When u is less than u/2 the grain is greater at
Greater
Margin
CURVES OF COOLING-EFFECTIVE CONTACT ZONE BROAD.

FIG. 3. This figure is based on Fig 1, and is for similar conditions. The full lines show tangents to the curve of grain of an injected igneous sheet (supposing the same to be proportional to the square root of the slowness of cooling) as derived from the approximate equations referred to in the text. The position of the point relative to the margin is represented by horizontal coördinates, the average linear dimensions of grain corresponding by vertical coördinates, while the decimals attached to each curve show the ratio corresponding to it of the consolidation-to the initial temperature. The lines in dashes are the actual curves sketched in, where they diverge markedly from the tangents.

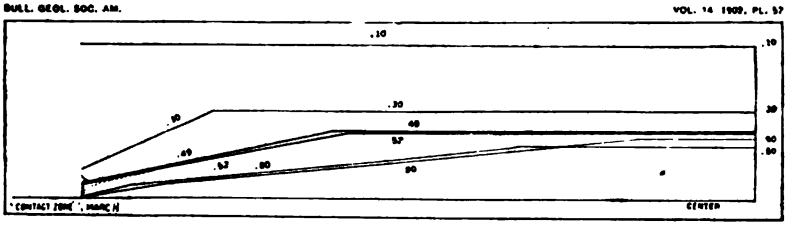

FIG. 4. Illustrating the variation of grain from margin, (to the left) to center (to the right) in flows, intrusive dikes, or sills which have a narrow contact zone, by the tangents to the curve of grain. The decimal figures adjacent to the curve indicate the ratio of the temperature of consolidation to that of initial injection or effusion, the temperature of the country rock being taken at 0°.

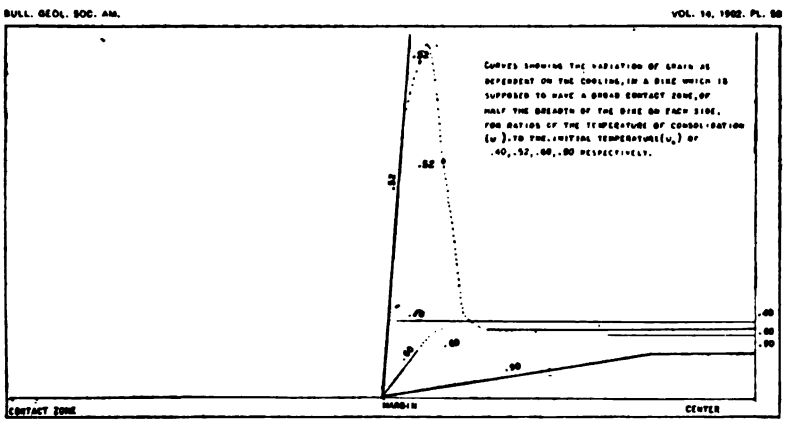

FIG. 5. Similar to Fig. 4, but illustrating the variation in grain in case the contact zone is broad. It stands in the same relation to Fig. 3 that Fig. 4 does to Fig. 2.

Many of the remarks and the theoretical results given below will be only slightly modified in case the above formula is not strictly true if only it be granted that the grain is some continuous expansible function of the slowness of cooling increasing with the same and zero when the latter is zero. In the Isle Royale report I worked out the theory of grain especially on the supposition that the top and bottom of the sheet were kept at a constant temperature, by water or air currents or otherwise, and found that this supposition illustrated by Fig. 1 fitted the facts fairly well for the augite of the Keweenawan traps and is an important help in studying the sections. Certain principles there enumerated it may be well to repeat here. It will be more convenient, however, to compare the grains by their linear dimensions than by the areas of their cross sections, and, if we call the average linear dimension[1] the grain, then:

(1). The grain will vary as the square root of the slowness of cooling.

[1] Determined by taking the largest grain in a number of different areas, usually five.

(2). Points at the same distance from a surface of fixed temperature will, if other conditions are similar and the grain was formed before the center cooled appreciably, have the same grain regardless of the size of the sheet. This was found experimentally to be true in the Keweenawan flows.

(3). The grain in such a case would be proportional to the distance from the bottom or top of the flow. This was found to be nearly true for the augite of a common type of flow mainly composed of labradorite and augite, and probably nearly a eutectic mixture, of which the Greenstone is a type.

This is illustrated in a plate of drill cores prepared for my next annual report while this is passing through the press.

This ratio of the increase of grain of the augite to the distance from the margin was found to be .0002, two millimeters for ten meters or about one inch for 400 feet. More accurate theory, as will be shown in this paper, indicates a more rapid increase close to the margin of the flow so that the first millimeter is attained within ten feet.

To illustrate the method of computation we will take the observations as given on page 245 of the Isle Royale report on thin sections 15252 to 15258 and reduce the distance to millimeters, allowing for fractions not given there. There is, however, an uncertainty of probably one-half of a foot (152 millimeters) in most of the distances. We obtain the table below:

Section.	Distance in mm.	Difference.	Grain in mm.	Difference.	Rate of difference = S = A or C.	Ax.	B.
15258	0	.....	0	.....	.....	.....	.....
	.....	296 ± 152	.....	1.2-5	.00422	.....	.....
5257	296 ± 152	.....	1.25	.....	.....	.06	1.19
	.....	7,054 ± 152	.....	1.65	.00022	.....	.....
15256	7,350 ± 152	.....	2.90	.....	.....	1.48	1.32
	.....	8,550 ± 152	.....	1.1	.00013	.....	.....
15255	15,900 ± 152	.....	4.	.....	.....	3.42	.58
	.....	6,200 ± 152	.....	1.	.00016	.....	.....
15254	22,100 ± 152	.....	5.	.....	.....	4.74	.26
	.....	6,800 ± 152	.....	2.	.00029	.....	.....
15253	28,900 ± 152	.....	7.	.....	.....	6.2	.80
	.....	8,600 ± 152	.....	2.—	.00023	.....	.....
15252	36,500 ± 152	.....	9—6	.....	.....	7.84	1.16
Average from 15257 to 15252					.00021	.....	.885

In this table the observations in thin-section 15258 are uncertain, for it is decomposed, and those on 15252 and 15253 are not very satisfactory, for the grain is so coarse that it would require a number of sec-

tions to give us a fair idea. It is obvious, however, that from 15257 clear in to the center, represented by 15252, the gradient is fairly steady and somewhere about .0002, which is what we found for the group on page 129 of the Isle Royale report (.06/304).

Taking the gradient from 15257 to the center, we find it to be (9–1.25)/(36,500—296) or .000213. Assuming this gradient from the margin, we find the column headed "Ax" and the difference between these and observed values will give us the average value of B. These differences are given in the column headed "B". Thus we can, as we shall later see, find the contact zone y', which equals B/A, or 2,400 millimeters.[1]

But we did not find this to be true for all flows, for there was another law in evidence:

(4). Other things being equal the greater the abundance of its constituent molecules, the coarser the grain.

Practical Applications.

Some practical applications of the above theories may be suggested.

1. A thick sheet of trap very fine grained as to ground mass is pretty sure to be a felsite or "ashbed diabase" = (porphyritic melaphyre or andose) type, more alkaline than the normal ophites.

2. From the coarseness of the lustre-mottling of even a small exposure of ophite a considerable bed may be inferred. For instance mottles an inch across would mean a bed some 800 feet thick. This may help to fill gaps in cross sections, and save trenching or exploring for amygdaloids uselessly near.

3. The direction in which the mottles or grain gets finer is probably (faults, etc., excepted) the direction of the nearest amygdaloid. Dr. Hubbard has used this successfully in cross cutting from shafts, and other exploratory work which he directed.

4. As Dr. Hubbard has suggested, if a flow appears by a chemical or petrographic analysis to be a normal ophite, but when cut by a drill hole or otherwise the grain does not increase at the normal rate of 400 feet per inch diameter of grain but at some other rate it might be possible to infer the dip.[2] But on account of the difficulty of determining the average rate of increase of grain accurately, and the liability of the drill hole to veer somewhat, and a possibility that an immediately succeeding flow may have modified the rate of increase this method can only be used with extreme caution, as a suggestion of probable dip. I have, however, used it.

5. In sinking or drifting sudden variations in grain may serve to call attention to faults and slips, and a normal diminution in grain forewarn of an amygdaloid or conglomerate.

In surface flows and for minerals formed immediately after the intru-

[1] I believe this is really too high, and that part of the coarseness of grain at the margin, which makes B and hence y so large, is formed in flowing. I suspect y' should be about two-thirds of the value used.

[2] The new rate would be (400 ÷ cos dip) feet per mile, in a vertical shaft or drill hole.

sion of a dike, before the temperature of the wall, which may be considered to start in at a temperature half way between that of the country rock and the intruded lava, has perceptibly varied, the facts agree nearly enough with the assumption of a constant marginal temperature, but in general we really ought to allow for a greater or less width of contact zone. In my Isle Royale report I showed how the contact zone could be allowed for, and yet I assumed that for the Keweenawan traps and corresponding intrusive diabases, the contact zone could be counted as insignificant. In this so far as the intrusives are concerned I was mistaken, and I also misled somewhat Mr. Queneau.[1]

He guided by Woodward, nevertheless, furnished a rapid method of computing the early and marginal temperatures, with the help of which I have been able to put the theory of intrusive sheets with a contact zone into much more calculable shape The labor of getting numerical results, and the apparent agreement of numerical results obtained in the Isle Royale report with the possibilities of the case, had previously led me to be too easily satisfied.

The following paper is strictly technical and puts the matter in more satisfactory shape.

General Formulæ for Rock Grain.

We may briefly summarize the results of the mathematical investigations as follows:

Marginal Temperature Fixed.

In an injected sheet of uniform temperature and diffusivity whose walls are kept at a fixed temperature the temperature may be expressed in two ways, the former most applicable at the early stages of cooling, the latter in the latter stages of cooling.

Curves showing the manner of cooling, at first fast at the margin and slow at the center, then later slow at the margin and faster at the center are given in Fig. 1.

$$(1)\quad \frac{u}{u_o} = P_m - (P_{m_o+m} - P_{m_o-m}) + (P_{2m_o+m} - P_{2m_o-m}) \text{ - - -}$$

$$(2)\quad \frac{\pi}{4}\,\frac{u}{u_o} = q \sin \pi\, x/c + \frac{q^9}{3} \sin 3\,\pi\, x/c + \frac{q^{25}}{5} \sin 5\,\pi\, x/c \text{ - - -}$$

where:

u is the temperature after a certain time (t);

u_o is the initial temperature;

t is the time from the beginning of cooling;

x is the distance from the margin;

c is the thickness of the flow;

a^2 is the diffusivity, K it was called in the article on soil temperatures.

[1] See "size of grain of igneous rocks in relation to the distance from the cooling wall," by Augustin L. Queneau. School of Mines Quarterly, XXIII, 181-195. January, 1902. Contributions from the Geological Department of Columbia University; Amer. Jour. Science. November, 1902, Volume XIV, page 393.

$m = x/2a\sqrt{t}$

$m_o = c/2a\sqrt{t} = c\,m/x$

nat log $q = -\pi^2 a^2 c^{-2} t = (\pi/2m_o)^2$

$P_m = \frac{2}{\sqrt{\pi}} \int_o^m - m^2 dm$

$\pi = 22/7 = 3.1416$

Formula (1) is the Woodward-Queneau formula and converges most rapidly at early times and near the margin when m_o is greatest.

This is apparent from the table below p. 222, in which P_m varies but little from 1 as soon as m is much over 2.

Formula (2) I used in the Isle Royale report[1] and converges much more rapidly for large values of t the time or q. When formula (1) ceases to give a result approximate to the third decimal place, a couple of terms of formula (2) will usually give it. The linear grain if we call $(T_1-T_2)\,dt$ and $(U_1-U_2)\,du$ will be expressed by the formula (where k depends on the power of crystallization of the mineral under the given conditions and will be *assumed* independent of the temperature and time, except as provided):

$$(3) \quad g = k\sqrt{\frac{dt}{du}}$$

For ordinary igneous magmas where probably according to Doelter du is often not over 40° and u_o and u are to be reckoned in hundreds of degrees dt and du may be treated by the infinitesimal calculus or that of finite differences.

In any table of the values of u in the terms of t, such as are given in Volume VI and here, we should find the ratio dt: du as the quotient of the corresponding consecutive differences of argument and functions respectively, for the same value of x^2.

But a glance at equation (2) shows, what is not so clear in (1), that it is only the ratios u/u_o, x/c and a/c which are involved in determining t, moreover our tables are not constructed directly with t as an argument, though u/u_o is the function. It will therefore be convenient to express (3) otherwise and introduce instead of t $m_o = \frac{c}{2a\sqrt{t}} = \frac{1}{2(a/c)\sqrt{t}}$

we have then:

$$(4) \quad g = \frac{k}{\sqrt{u_o}} \cdot \frac{c}{a} \sqrt{\frac{-dm_o}{2m_o^3}} \sqrt{\frac{1}{-du/u_o}}$$

Now in studying the variation of grain from center to margin in any one sheet $\frac{ck}{a\sqrt{u_o}}$ may be supposed not to vary. I have denoted it by K. The expression $\sqrt{-du/u_o}$ if u/u_o and $\frac{x}{c}$ be given may be found from the tables on pages 221 and 222 by subtracting successive values of u/u_o and so may be the expression $\sqrt{\frac{-dm_o}{2m_o^3}}$ or an average value of the same which is the same for any column of the table I.

[1] See Byerly, Fourier's series, Article 60, ex. 1.
[2] I. e. we deal with the partial derivative of t relative to u, x being supposed constant.

We may write:

$$(5)\ \frac{c}{a}\sqrt{\frac{-dm_o}{2m_o^3}} = f\left(\frac{x}{a}, \frac{u}{u_o}, \frac{a}{c}\right) = \frac{c}{a}M_o = \frac{x}{a}\sqrt{\frac{-dm}{2m^3}} = \frac{x}{a}M = \sqrt{dt}$$

so we have $g = KM_o/\sqrt{du/u_o}$.

It is also at times worth while to replace dt by

$$d\left(m = \frac{x}{2a\sqrt{t}} = \frac{x/c}{2a/c\sqrt{t}}\right)$$

dt (a partial derivative,—x constant)$= \frac{x}{a}\sqrt{\frac{-dm}{2m^3}}$ and

$$(7)\ g = \frac{k}{\sqrt{u_o}}\frac{x}{a}\sqrt{\frac{-dm}{2m^3}}\sqrt{\frac{1}{du/u_o}} = K.\frac{x}{c}\sqrt{\frac{-dm}{2m^3}/d\,u/u_o}.$$

From equation (1) and table (2) it appears that when $m_o > 2.5$ $u/u_o = P_m$ so that $m = P^{-1}\ u/u_o$ and although theoretically and in general a function of x,m is so no more. Moreover if u/u_o is small m is nearly proportional to it and $m = \sqrt{\pi/4}\ u/u_o = \frac{1}{1.125}\frac{u}{u_o} = .8863\ u/u_o$.

If therefore we assume

$$(8)\quad h = \sqrt{\frac{-dm : (u/u_0)^3}{-du/u_0 : m^3}}$$

it will be for a considerable range of temperature close to .8863, for a still wider range be $\frac{u/u_0}{m}$, and for all early times be practically independent of t so that it will be convenient to introduce it in (7) and find

$$(9)\quad g = K.\frac{x}{c}\cdot\frac{1}{h\sqrt{2\,(u/u_0)^3}}$$

$$(10)\quad g = C\,x \text{ where } C = \frac{K}{ch\sqrt{2\,(u/u_0)^3}}$$

and C in early times, i. e. for the grain close to the margin, is a function of u/u_0 and of K/c, i. e., k, a, and u_O, not involving c nor x.

As soon as the cooling has proceeded so far that there is a belt of uniform grain at the center (the cooling is expressed by the first term of Eq. 2) the grain at the center E may be written [1].

$$(11)\quad g = E = K/\pi\sqrt{u/u_o}$$

Suppose we have the rate of increase of grain at the margin determined by observation and also the grain at the center. Then we may determine when at the rate of increase at the margin continued the grain would be of a coarseness equal to that at the center.[2] We may call this (x′) the width of the belt of increasing grain. It is:

$$(12)\quad \frac{x'}{c} = \frac{E}{C} = \frac{h\sqrt{2}}{\pi}\frac{u}{u_O} = .4\ u/u_O$$

[1] From (3) by differentiation of the first term of (2).
[2] Point of intersection of the tangents to the curve of grain at center and at margin.

Marginal Temperature Not Fixed.

When we come to consider the case that the sheet is supposed to have a heated contact zone, we find it again important to consider the conditions close to the margin and those at the center, for in each case we find relatively simple expressions for the grain, though the intermediate grain does not depend on them so simply.

First, we can see that a formula which we found in the Isle Royale report will enable us readily to construct the curves of decreasing temperature, which are shown in figures 2 and 3, in the former when the contact zone supposed heated is narrow and in the latter when it is as wide as the distance to the center of the dike.

This formula is as follows:—If v represents the temperature at a time t of a point at a distance of z from the center of a sheet the thickness of which is 2w with a contact zone of breadth y on either side, so that the whole zone affected or c is equal to 2w+2y. then—

$$(13) \quad v = \tfrac{1}{2}(u_{w+z} + u_{w-z})$$

where u_{w+z} is the temperature which would exist at the same time t after the beginning of cooling and conditions otherwise the same (except that its margins are kept at a constant temperature) in a sheet whose thickness was equal to c at a distance of w+z from the margin and u_{w-z} is the temperature at a point at a distance of (w–z) from the margin in the same sheet. Or if (w–z) becomes negative—that is, the point lies in the contact zone—we must assume

$$(14) \quad u_{w-z} = -u_{z-w} \text{ (in the contact)}$$

Now if we let x′ be the distance of the point in the sheet with a contact zone from the margin of the sheet—that is $x' = \frac{c}{2} - z - w$

$$(15) \quad v = \tfrac{1}{2}(u_{x'+2y} + u_{x'})$$

So if we take y to be $\frac{1}{24}$ of c, then for various values of x′ from 0 to 11 the center we shall have as corresponding values of v respectively one-half the values of curve 2 of 1, values half way between curves 1 and 3, 2 and 4, 4 and 6, 5 and 7, 6 and 8, 7 and 9, 8 and 10, and at the center the values of curve 11 for the same time. These curves are drawn in Fig. 2 which illustrates, the cooling, therefore, in case the contact zone affected is only narrow.[1]

Similarly if y be 6, the margin will have half the values of curve 12 Fig. 3 and the center will have the values of curve 6 for the same times. Thus we can obtain the curves of these figures either graphically (very rapidly) or by taking means of appropriate rows of the table of solutions of the case where the margin is kept at a fixed temperature, a table which is given in the Isle Royale report for an initial temperature of .7854, and here for the initial temperature of 1. (Table I.)

Thus expressing the grain of the sheet with a contact zone y on each side as a certain function g ( ) of x′, of u the temperature of crystallization of u_o temperature of injection, of y the width of the contact zone

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[1] One might ask, why should narrow and broad contact zones be assumed? The answer would be, to allow for the varying diffusivity of the country rock and its capacity to absorb heat by the convection or evaporation of water, or by chemical reactions.

and of k, to include all other factors, such as diffusivity, crystallization power, etc., we have:

AT THE CENTER.

Here.

(16) $v = u_w$ whence we have

(17) Center grain

$g\,(k, x = c/2, v, u_o, y, c) = g\,(k, x = w, u_w, u_o, y = o, c.)$

The expression for the grain at the center will be then,

(18) $g\,(k, x = c/2 \text{ or } x' = w, u, u_o, y, c) = \frac{k}{\sqrt{u_o}}\sqrt{dt}/\sqrt{-du/u_o}$

$= K\,\frac{a}{c} f\left(\frac{w}{c}, \frac{v}{u_o}, \frac{a}{c}\right)\sqrt{-dv/u_o}.$

In this expression and in the table we must confine ourselves to the row for which most nearly $x = w/c$, and find the point for which most nearly u/u_o has the value v/u_o, and then interpolate to find $\frac{a}{c} f\left(\frac{w}{c}, \frac{v}{u_o}, \frac{a}{c}\right)$. Or if the cooling has gone on so far that there is a belt of constant grain at the middle ($m_o > 2.5$ practically) by Eq. 11.

(19) $g\,(k, x = \frac{c}{2} \text{ or } x' = w, u, u_o, y, c) = \frac{K}{\pi\sqrt{u/u_o}} = E$

AT THE MARGIN.

(*Consolidation temperature nearer that of country rock.*)

Here.

(20) $v = \frac{1}{2}\, u_{2y}$ whence we find that the grain at margin if $u < u_o/2$ is, since $\sqrt{dv} = \frac{\sqrt{du}}{\sqrt{2}}$.

(21) $g\,(k, x = y \text{ or } x' = 0, v, u_o, y, c) = \sqrt{2}\, g'\,(k, x = 2y, u, u_o, y = o, c)$,

or in general,

$$g\,(k, x' = o, u, u_o, y, c) = \sqrt{2}\,\frac{K}{\sqrt{u_o}}\sqrt{dt}/\sqrt{du/u_o}$$

$$(22)\quad = K\sqrt{2} f\left(\frac{2y}{c}, \frac{u}{u_o}, \frac{a}{c}\right)/\sqrt{du/u_o},$$

or if u/u_o is so low that this value falls in the second period, i. e., $m_o < 2.5$.

(23) $g\,(k, x' = o, u, u_o, y, c) = K\sqrt{2}/\pi\sqrt{u/u_o} = K/\pi\sqrt{v/u_o}.$

Comparing equations (22) and (23) with (18) and (19) we infer that if the temperature of consolidation is low enough the grain may be the same from center to margain. Otherwise it will be coarser at the margin if $u < u_o/2$.

(*Consolidation temperature nearer that of injection.*)

In as much as $v = 1/2\, u_{2y}$ at the margin, so long as u_{2y} has not dropped from u_o, v will be equal to $u_o/2$. During this time the cooling will be as though the temperature at the margin were fixed at 0. It

will be the same as that of a sheet of constant marginal temperature (which is taken as 0) of which the initial temperature will be $u_o/2$ and u will be $v-\frac{u_o}{2}$. In as much as we have expressed the grain in terms of the ratio u/u_o we can now write

(24) $g\,(k,\ x=x'+y,\ v,\ u_o,\ y,\ c)=g\,(k,\ x',\ v-\frac{u_o}{2},\ \frac{u_o}{2},\ 0,\ 2w)$,

where $2w=c-2y$ and going back to equations 3 to 10 we find from (4) and (5)

(25) $$g=\frac{k}{\sqrt{\frac{u_o}{2}}}\cdot f\left(\frac{x'}{2w}\cdot\frac{2v}{u_o}-1,\ \frac{a}{2w}\right)\Big/\frac{1}{\sqrt{-d\left(\frac{2v}{u_o}-1\right)}}$$

(26) $$=\frac{K}{c}\cdot\frac{x'\quad\sqrt{2}}{-h'\sqrt{2\left(\frac{2u}{v_o}-1\right)^3}}=C'x'$$

Where h′ stands in the same relation to $\frac{x'}{2w}\cdot\frac{2v}{u_o}-1$ as h to $\frac{x}{c}$ and $\frac{u}{u_o}$, i. e., h′ is for points close to the margin crystallized in early times independent of $\frac{x'}{2w}$, and this will be true for the linear rate of increase of grain (tangent to the curve of grain) at the margin, and while it depends on $\frac{2v}{u_o}-1$ it will vary only between .7 and 9. if $\frac{2v}{u_o}-1$ is less than .966, i. e., $\frac{v}{u_o}$ is $<.984$. That is unless the crystallization is practically coincident with the consolidation h′ is roughly constant.

(27) $$h'=\sqrt{\frac{-d\,\frac{x'}{2a\sqrt{t}}}{d\left(\frac{2v}{u_o}-1\right)}\left(\frac{\frac{2v}{u_o}-1}{\frac{x'}{2a\sqrt{t}}}\right)^3}$$

$$=\frac{a}{x'}\sqrt{\frac{dt}{d\,\frac{2v}{u_o}-1}\cdot\left(\frac{2v}{u_o}-1\right)^3}=\frac{2w}{x'}\left(\frac{a}{2w}\cdot\sqrt{dt}\right)\sqrt{\frac{\left(\frac{2v}{u_o}-1\right)^3}{d\,\frac{2v}{u_o}-1}}$$

$$=\frac{2w}{x'}(M_o)\sqrt{\frac{\left(\frac{2v}{u_o}-1\right)^3}{d\,\frac{2v}{u_o}-1}}$$

in which t is a function of $\frac{x'}{2w}$ and $\frac{2v}{u_o}-1$ and $\left(\frac{a}{2w}\sqrt{dt}\right)=M_c$ must be taken from the table I, using $\frac{x'}{2w}$ for the distance, $\frac{2v}{u_o}-1$ for the temperature.

Intermediate Zone.

We observe in figure 2 that the curve of cooling of the extreme margin thus indicated soon becomes coincident with a curve of cooling of the sheet of reference Fig. 1 with width c and fixed marginal temperature of 0. If that is so,

$$(28) \quad v = \tfrac{1}{2} u_{2y} = u_{y'}$$

when 2y represents the distance of the curve of cooling of the sheet of reference with which it becomes coincident. If the cooling has gone so far that it can be represented by the first term of $\frac{\pi}{4} \frac{u}{u_0} = q \sin \pi \frac{x}{c}$, we can see that (24) can be true and that

$$(29) \quad \frac{\pi}{4} \frac{v}{u_0} = \frac{1q}{2} \sin \frac{\pi\ 2y}{c} = q \sin \frac{\pi\ y'}{c}$$

gives us a simple equation to solve to find y′, which can always be found.

$$(30) \quad \frac{\pi\ y'}{c} = \sin^{-1} \tfrac{1}{2} \sin \pi \frac{2y}{c}$$

But we also see that if y is so small, that is, the contact zone so small, that $\sin 2\pi y'/c$ is proportional to $2\pi y/c$ then y′ will be the same proportional to y, and more generally, if it is so small that $\sin n\pi y/c$ is proportional to $n\pi y/c$ to the number of terms of (2) covered by n will y′ be proportional to y and eq (28) be true. Not only that, but in equation (1) if $v/u_0 = P \frac{y'}{2a\sqrt{t}}$ and $P \frac{2y'}{2a\sqrt{t}}$ is nearly proportional to $\frac{y'}{2a\sqrt{t}}$ which it is if $\frac{v}{u_0} < .33$, then to the same extent will:

$$(31) \quad \frac{v}{u_0} = \tfrac{1}{2} \frac{u_{2y}}{u_0} = \tfrac{1}{2} (\text{constant} \times) \frac{2y}{2a\sqrt{t}}$$

$$= (\text{constant} \times) \frac{y'}{2a\sqrt{t}}$$

and $v = u_{y'}$.

That is to say if the contact zone y is small enough so that $2v = u_{2y}$ becomes .33 before the center has cooled perceptibly,[1] or the marginal temperature becomes say 1/6 of the initial, the cooling at that margin will be the same as at a corresponding point of the sheet of reference whose walls are kept cold. At the same time the cooling at the center is the same as that of another sheet in the reference sheet, at a distance $\frac{c}{2} - y$ from the wall. The cooling on two planes, center and margin being the same as on two planes of the reference sheet, the cooling between must be the same, except that due allowance must be

[1] And table I shows that 2y must be about $\frac{1}{24} \frac{x}{c}$, for then when the temperature at the center is still .9626, the temperature for $x = \frac{2c}{24}$ is .3048.

made for the different distance apart of the two sets of planes. The distance of corresponding planes being thus proportional we obtain a formula:

$$(32)\quad g\,(k, x, u, u_o, y, c,) = g\,\left(k, \frac{c-2\overline{y+y'}}{c-2y}\,x'+y', u, u_o, 0,\right)$$

if $2 \sin y\ \pi c = \sin 2\ y\ \pi c$ nearly.

At the center formula (32) reduces to formula (18) and writing (32) (29) $= g = Ax' + B$ and comparing it with (3), (7) and (9) we find

$$(33)\quad A = \frac{K}{c}\,\frac{c-2y-2y'}{c-2y}\cdot\frac{1}{h\sqrt{2(u/u_o)^3}}$$

$$(34)\quad B = K\,\frac{y'}{c}\cdot\frac{1}{h'\sqrt{2(u/u_o)^3}}$$

The equation (29) is the equation of another tangent to the curve ordinarily or a line parallel to one. It will only appear in the case of small contact zones at the point of minimum curvature. It may be distinguished from the other tangent to the curve of grain by the fact that it does not give a 0 grain at the margin. We notice, too, that

$$(35)\quad \frac{B}{A} = y'\cdot\frac{c-2y}{c-2y-2y'} = y'\cdot\frac{2w}{2w-2y'} = y'\cdot\frac{w}{w-y'}$$

This is always positive unless $y + y' > 1/2$, i. e., unless the contact zone is greater than the width of the dike $> c/4$ on each side, and is for small contact zones practically proportional to the contact zone.

If a series of observations of grain give a value of B negative or very small it is pretty likely that they refer to the equation $y = C' x'$ and that the value of B is due to the errors of observation.

From the formulæ above given not only can the grain be roughly constructed from the data K, u, u_o, y and c, but more important still, conversely if from observation we can construct the curve of grain for a given mineral with such accuracy that we can locate the tangents in question we can then draw inferences regarding the size of the dike, and the heat at injection.

From the curves of grain we may infer the order of crystallization of the different minerals.

A glance at a few typical curves of grain will show us what inferences may be drawn without any special calculation. Fig. 4 shows a number of curves of grain of different values of u/u_o and a small contact zone. Fig. 5 gives curves of grain when the contact zone is large. As the contact zone becomes smaller and smaller the curves approach those appropriate to the case when the contact belt is kept at a constant temperature.

We may make the following comments:

(1) The shape of the curves depends wholly on the ratio of the initial temperature to that of the crystallization of the mineral whose grain we are studying.

(2) Unless these temperatures are very close together, however, the grain at the center does not vary with their ratio, but is proportional to

($kc/a\sqrt{u_o}$), being greater the greater the size of the sheet and the less the diffusivity and temperature of consolidation.

The last condition may be put more suggestively by saying that the grain at the center is greater the nearer the temperature of the country rock is to the temperature of consolidation.

(3) The grain at the margin should be 0 if the initial temperature is more than twice the temperature of consolidation.

(4) The grain will be greater at the margin than at the center if the initial temperature is more than twice the temperature of consolidation, but if it is much more the grain will be practically even throughout, as with some aplites (curve .40 of Fig. 5).

(5) If there is a broad contact zone and the initial temperature is not far below twice the temperature of consolidation, there will be a belt of coarsest grain not at, but parallel to the margin (curve .52 of Fig. 4).

(6) When the contact zone is quite small and the initial temperature below the twice the temperature of consolidation the increase of grain will at first be linear and very rapid, then the linear and less rapid. This leads to the following practically somewhat puzzling uncertainty.

Suppose we have found by observation a nearly linear increase of grain. We can then locate a tangent to the curve of grain, which will be either that of formula (9) or that of formula (11). But which? Theoretically we can tell by this sign that the equation of (26) should lead to a value of the grain at the margin of zero, while the equation (29) should not lead to a value of 0 at the margin, but one of B, proportional to the effective contact zone y'.

Practically, unavoidable errors, of observation will be shown by a divergence of the equation from giving a zero value of the grain at the margin, even if it is really referrible to the equation (26) $g = C'x'$. But if the values of B come out negative, indicating a negative contact zone, they are likely to be due to error, and once more as C' is independent of the width of the dike or of the contact zone it is more likely to be fairly uniform for the same type of rock.

(36). Thus from (19) to (26) we find: $$\frac{E_4}{C'c} = \frac{h'}{\pi}\sqrt{\frac{(2\frac{v}{u_o}-1)^3}{v/u_o}}$$

As long as u/u_o is low enough, i. e., < .80 eq (36) expresses the relation of $E/C'c$. We can construct a curve or compute a table to express $E/C'c$ in the terms of v/u_o (Fig. 6) and from such a curve and the observation of the grain at the middle, the rate of increase of grain at the margin and the probable breadth of the zone affected $c = 2w + 2y$ we can at once infer the ratio of the crystallization temperature to the initial temperature. In this expression the actual width of the dike or the ratio of contact zone to dike does not appear. This is because by the time the temperature has dropped to .80 uo the contact zone and dike are cooling together as one mass.

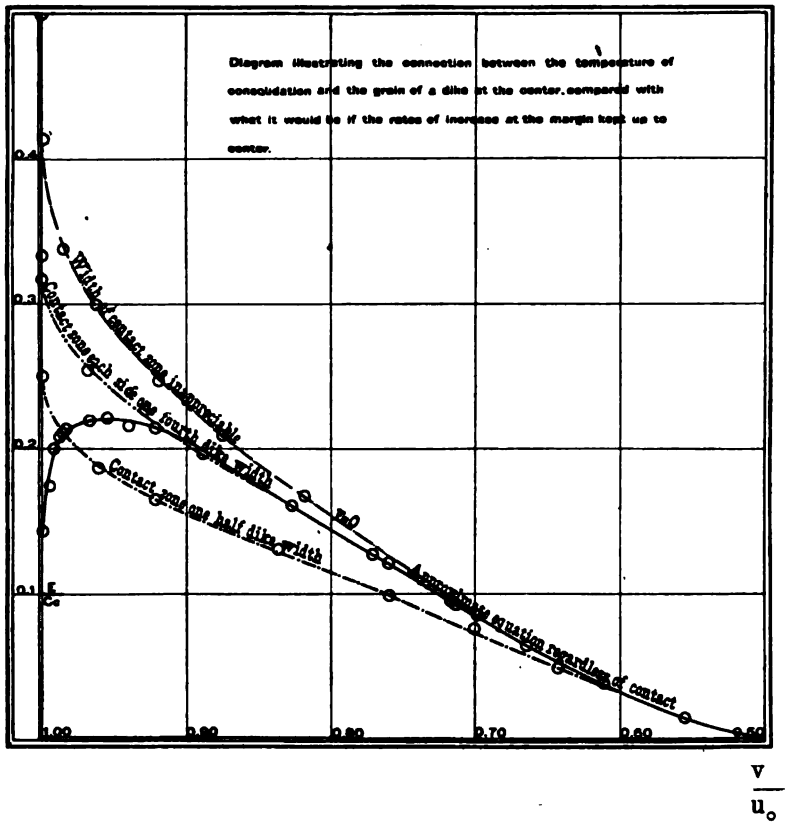
Diagram illustrating the connection between the temperature of consolidation and the grain of a dike at the center, compared with what it would be if the rates of increase at the margin kept up to center.
Width of contact zone inappreciable
Contact zone each side one fourth dike width
Contact zone one half dike width
Parabola
Approximate equation regardless of contact
0.4
0.3
0.2
0.1
E/C'c
1.00
0.90
0.80
0.70
0.60
0.50
v/u₀

FIG. 6. Showing E/C'c or the ratio of the grain at the center to that which would be reached if the rate of increase at the margin C' kept up for a distance c, equivalent to the whole zone affected.

But if the crystallization is earlier and we have to use eq. (18) instead of eq. (19) it will not be so. The actual grain will diverge from that of E and $\frac{E}{C'c}$ from that given by (36). But as the crystallization temperature approaches u / u_o as we have seen the increase of grain becomes more and more linear and E approaches $\frac{C'w}{C'c} = \frac{w}{c}$. An ordinary range of contact zone may perhaps be from $y = o$ to $y = w$, and for that range of contact zone, the point which $\frac{E}{C'c}$ approaches will range from .5 to .25. The accompanying figure 6 gives $\frac{E}{C'c}$ for various values of u/u_o and also the ratio of $E/C'c$ as derived assuming three values of y, to wit: $y = o$, $y = \frac{w}{2}$, and $y = w$ and computing as follows: Going back to (18) we have for the center $g = K\frac{a}{c} f\left(\frac{w}{c}\ \frac{v}{u_o}\ \frac{a}{c}\right) \sqrt{-dv/u_o} = KM_o / \sqrt{-dv/u_o}$. We will

assume y = 0 then $\frac{w}{c} = 1/2$ and we must use the row 12 $\left(\frac{x}{c} = \frac{12}{24}\right)$ of table I. Taking this row we notice that $\frac{v}{u_o}$ dropped from .8742 to .7597 when M_o has the average value of .1234. Accordingly $\frac{g}{K} = \frac{.1234}{\sqrt{.1145}} = .368. = \frac{E}{K}$

The average value of the temperature we will take for this interval to be $\frac{(.8742 + 7597)}{2} = .8169$. Then $\left(\frac{2v}{u_o} - 1\right)$ will be .6338. Now for the temperature at the margin table II holds, and we find $P^{-1}\left(\frac{2v}{u_o} - 1\right) = m'$ $= \frac{x'}{2a\sqrt{t}}$ to be .630. Taking the nearest differences we find that for an increase in m′ from .63 to .64 or dm′ = .0100 there is a change in Pm′ or $\left(2\frac{v}{u_o} - 1\right)$ of .0076 so that going back to (27) and (26)

$$\frac{cg}{Kx'} = \frac{cC'}{K} = \sqrt{2}\,\frac{1}{\sqrt{.0076}}\sqrt{\frac{.0100}{2(.6338)^3}\,\frac{(.630)^2}{(.6338)^2}}$$

$$= \frac{1}{.445}$$

Thus the ratio of grain at center E/K to c C′/K is

$$\frac{E}{cC'} = .368 \Big/ \frac{1}{.445} = .165^1$$

Similarly we may go on to compute the values for the drop of temperature given by values of the temperature in the same row and adjacent columns of table I. Each row will correspond to a different value of the contact zone. C′ c/K may be also found and the quotient, E/C′c Some of their values are shown in Table III below and the curves showing the dependence of E/C′c upon v/u_o are shown in figure 6 for different contact zones.

In a very rough way the value of the actual grain relative to C′ c is proportional to the amount by which the temperature of crystallization is nearer the initial temperature than the country rock temperature. In fact if the contact zones have the width of the dike the actual grain E is to the grain which there would be if the marginal increase continued to the center $\left(\text{i. e., } \frac{C'c}{4}\right)$ very roughly as the amount by which the consolidation temperature is nearer to the initial temperature and exceeds the consolidation marginal median temperature, is to the median temperature.

[1] These calculations are made with a slide rule and are not very accurate.

TABLE I.

Of u / u_o when $u_o = 1$ for various values of x (distance from margin) and q; ($-$ dec log $q = 1.0715\ m_o^2$).

x':c	1.00	.99	.98	.97	.96	.95	.94	.93	.92	.91	.90	.80	.70	.60	.50	.40	.30	.20	.10	q = 0.00	$\frac{x}{c} 24$
.0416	1.0000	0.6444	0.4852	0.4040	0.3613	0.3172	0.2835	0.2688	0.2519	0.2363	0.2241	0.1553	0.1229	0.1013	0.0834	0.0665	0.0499	0.0332	0.0117	0	1
.0833	1.0000	.9353	.8058	.7111	.6404	.5862	.5309	.4964	.4897	.4533	.4217	.3048	.2372	.2007	.1653	.1319	.0966	.0658	.0329	0	2
.1250	1.0000	.9968	.9493	.8102	.8306	.7810	.7357	.6973	.6635	.6341	.6077	.4133	.3569	.2975	.2443	.1950	.1428	.0974	.0487	0	3
.1666	1.0000	1.0000	.9909	.9660	.9331	.8977	.8632	.8306	.8002	.7719	.7459	.5667	.4521	.3861	.3190	.2547	.1910	.1273	.0637	0	4
.2083	1.0000	1.0000	.9999	.9919	.9779	.9590	.9372	.9193	.8910	.8682	.8460	.6882	.5584	.4690	.3883	.3100	.2325	.1550	.0775	0	5
.2500	1.0000	1.0000	1.0000	.9973	.9940	.9858	.9744	.9607	.9455	.9294	.9129	.7598	.6422	.5308	.4508	.3602	.2701	.1759	.0900	0	6
.2916	1.0000	1.0000	1.0000	.9997	.9986	.9959	.9909	.9838	.9751	.9651	.9541	.8289	.7135	.6077	.5054	.4040	.3030	.1974	.1010	0	7
.3333	1.0000	1.0000	1.0000	1.0000	.9996	.9989	.9971	.9940	.9897	.9841	.9766	.8813	.7718	.6616	.5513	.4410	.3308	.2204	.1102	0	8
.3750	1.0000	1.0000	1.0000	1.0000	1.0000	.9997	.9993	.9980	.9961	.9933	.9897	.9189	.8168	.7041	.5878	.4704	.3528	.2352	.1149	0	9
.4166	1.0000	1.0000	1.0000	1.0000	1 0000	.9999	.9996	.9994	.9985	.9974	.9956	.9437	.8488	.7349	.6141	.4919	.3689	.2459	.1229	0	10
.4583	1.0000	1.0000	1.0000	1.0000	1.000	1.0000	.9999	.9998	.9995	.9990	.9981	.9580	.8678	.7534	.6306	.5048	.3787	.2524	.1262	0	11
.5000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	.9999	.9997	.9994	.9987	.9626	.8742	.7597	.6357	.5091	.3819	.2546	.1273	0	12
	Inf.	15.673	11.053	8.9994	7.774	6.9347	6.3149	5.8305	5.4905	5.1146	4.8389	3.325	2.64	2.20	1.834	1.645	1.435	1.24	1.035	0	m_o
					.0319	.0323	.0325	.0328	.0333	.0334	.0335	.1056	.1144	.1234	.1370	.1684	.1701	.20	.264	.604	M_o

TABLE II.

Values of the probability integral, P_m: Sometimes $= u / u_o$, if $m = \frac{x}{2a\sqrt{t}} = \frac{x}{c} m_o$.

m	0	Difference.	1	Difference.	2	Difference.	3	Difference.	4	Difference.	5	Difference.	6	Difference.	7	Difference.	8.	Difference.	9
0.0	0.0000	113	0.0113	113	0.0226	112	0.0333	113	0.0451	113	0.0564	112	0.0676	113	0.0789	112	0.0901	112	0.1013
0.1	.1125	111	.1236	112	.1348	111	.1459	110	.1569	111	.1680	110	.1790	110	1900	109	.2009	109	.2118
0.2	.2227	108	.2335	108	.2443	107	.2550	107	.2659	106	.2763	106	.2860	105	.2974	105	.3079	104	.3183
0.3	.3286	103	.3389	102	.3491	102	.3593	101	.3694	100	.3794	099	.3893	099	.3992	098	.4090	097	.4187
0.4	.4284	096	.4380	095	.4475	094	.4569	093	.4662	093	.4755	092	.4748	090	.4937	090	.5027	090	.5117
0.5	.5205	087	.5292	087	.5379	086	.5465	084	.5549	084	.5633	083	.5716	082	.5798	081	.5879	080	.5959
0.6	.6039	078	.6117	077	.6194	076	.6270	076	.6346	076	.6520	074	.6494	072	.6566	072	.6638	070	.6708
0.7	.6778	069	.6847	067	.6914	067	.6981	066	.7017	065	.7112	063	.7175	063	.7238	062	.7300	061	.7361
0.8	.7421	059	.7480	058	.7538	057	.7595	056	.7651	056	.7707	054	.7761	053	.7814	053	.7867	051	.7918
0.9	.7969	050	.8019	049	.8068	048	.8116	047	.8163	046	.8209	045	.8254	045	.8299	043	.8342	043	.8385
1.0	.8427	041	.8468	040	.8508	040	.8548	038	.8586	038	.8624	037	.8661	037	.8698	035	.8733	035	.8768
1.1	.8802	033	.8835	033	.8868	032	.8900	031	.8931	030	.8961	030	.8991	029	.9020	028	.9048	028	.9076
1.2	.9103	027	.9130	025	.9155	026	.9181	024	.9205	024	.9229	023	.9252	023	.9275	022	.9297	022	.9319
1.3	.9340	021	.9361	020	.9381	019	.9400	019	.9419	019	.9438	018	.9456	017	.9473	017	.9490	017	.9507
1.4	.9523	016	.9539	015	.9554	015	.9569	014	.9583	014	.9597	014	.9611	013	.9624	013	.9637	012	.9649
1.5	.9661	012	.9673	011	.9684	011	.9695	011	.9706	010	.9716	010	.9726	010	.9737	009	.9745	010	.9755
1.6	.9713	009	.9722	008	.9730	010	.9788	008	.9796	008	.9804	007	.9811	007	.9818	007	.9825	007	.9832
1.7	.9838	006	.9844	006	.9850	006	.9856	005	.9861	006	.9867	005	.9872	005	.9877	005	.9882	004	.9886
1.8	.9891	004	.9895	004	.9899	004	.9903	004	.9907	004	.9911	004	.9915	003	.9918	004	.9922	003	.9925
1.9	.9928	003	.9931	003	.9934	003	.9937	002	.9939	003	.9942	002	.9944	003	.9947	002	.9949	002	.9951
2.0	.9953	002	.9955	002	.9957	002	.9959	002	.9961	002	.9963	001	.9964	002	.9966	001	.9967	002	.9969
2.1	.9970	002	.9972	001	.9973	001	.9974	001	.9975	001	.9976	001	.9977	002	.9979	001	.9980	.....	.9980
2.2	.9981	001	.9982	001	.9983	001	.9984	001	.9985	.....	.9985	001	.9986	001	.9987	.....	.9987	001	.9988
2.3	.9989	.....	.9989	001	.9990	.....	.9990	.....	.9991	.....	.9991	001	.9992	.....	.9992	.....	.9992	001	.9993
2.4	.9993	.....	.9993	001	.9994	.....	.9994	000	.9994	001	.9995	.....	.9995	.....	.9995	.....	.9996	001	.9996
2.5	.9996	.....	.9996	.....	.9996	.....	.9997	.....	.9997	.....	.9997	.....	.9997	.....	.9997	.....	.9997	011	.9998
2.6	.9998	.....	.9998	.....	.9998	.....	.9998	.....	.9998	.....	.9998	.....	.9998	.....	.9998	.....	.9998	001	.9999
2.7	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2.8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.9999	001	.....	.....	.....	.....	.....

TABLE III.

Ratio of grain at center to C' c.

if y=0		y=1/2 w		y=w		General Approximate.	
v/u$_o$	E/C'c	v/u$_o$	E/C'c	v/u$_o$	E/C'c	v/u$_o$	E/C' c by eq. 36
1.0000	.500	1.0000	.333	1.0000	.250	1.0000	h'/ π
.9998	.46	.9998	.318	.....	....	.9973	143
.99905	.413	.9982	.254	.....	....	.9964	155
.9856	.338	.....	....	.9858	.212	.9945	174
.9626	.299	.....	....	.9607	.1873	.9919	200
.9183	.247	.9290	.227	.9212	.1648	.9881	208
.8742	.209	.8813	.1965	.8363	.1301	.9830	213
.8169	.167	.8265	.1597	.....	....	.9670	219
.6977	.855	.7718	.1265	.7598	.0987	.9551	221
.....	....	.7167	.0941	.7010	.0752	.9401	216
.....	....	.....	....	.6422	.0487	.9213	214
.....	....	.....	....	.....	....	.8984	204
.....	....	.....	....	.....	....	.8710	188
.....	....	.....	....	.....	....	.8389	168
.....	....	.....	....	.....	....	.8020	145
.....	....	.....	....	.....	....	.7602	121
.....	....	.....	....	.....	....	.7142	093
.....	....	.....	....	.....	....	.6643	067
.....	....	.....	....	.....	....	.6112	038
.....	....	.....	....	.....	....	.5557	014
.....	....	.....	....	.....	....	.5000	000

Whenever $u/u_o = P_m$ h is independent of x and we have the following table:

TABLE IV.

$P_m = u/u_o$	m	$h = \sqrt{\frac{m^3 D_m u\ u_o}{(u\ u_o)^3}}$
0	0	$\sqrt{\pi \cdot 4}$
.1125	.1	.8863
.2227	.2	.88
.3286	.3	.88
.4284	.4	.88
.5205	.5	.88
.6039	.6	.87
.6778	.7	.87
.7421	.8	.86
.7968	.9	.85
.8427	1.0	.83
.8802	1.1	.80
.9103	1.2	.78
.9340	1.3	.75
.9661	1.4	.70
.9763	1.5	.67
.9838	1.6	.64
.9891	1.7	.55
.9928	1.8	.49
.9953	1.9	.45
1.0000	0.0	.00

Approximate Formulæ.

Now, if we suppose that we can make certain simplifications, which can often be done, we can obtain approximate formulae which are very easy to handle. We will assume that y is equal to y′ and that the fraction $\frac{c-(2y+y')}{c-2y} = 1$. This we may do when the contact zone is relatively small. We will also introduce h′ as before and call $v/u_o = f^2$. Also we will call the expression $(k\,c/a\sqrt{u_o})$ K and we have the following formulæ:

(40). $C' = K/ch'(2v/u_o - 1)^{\frac{1}{2}} = K/ch'(2f^2 - 1)^{\frac{1}{2}}$ from (26 and 27) As $K/c = k/a\sqrt{u_o}$, C′ is independent of the size of the dike or the contact zone.

(41) $A = K/ch(v/u_o)^{\frac{1}{2}}\sqrt{2} = K'/chf^2\sqrt{2}$, from (33).

(42) $B = Ky'/ch(v/u_o)^{\frac{1}{2}}\sqrt{2} = Ky'/chf^2\sqrt{2}$, from (34).

(43) $E = K/\pi\sqrt{v/u_o} = K/\pi f$ from (19).

From (41) and (42) we can determine y′, the effective contact zone, which is B/A.

(44) $y' = \frac{B}{A}$.

If y is less than 1/12 of c, we may be sure that so far as the contact zone is concerned our approximate solutions are pretty close. From (41) and (43) we can find c in the terms of A, E and K—that is, we can sometimes by observation of the grain determine the thickness of the dike when it was not previously known. Moreover, we can find f in the terms of A, E and c, and if f^2 does not come too near to unity we may feel that our approximate formulæ and results from them are not likely to be far out. We can also find K in the terms of A, E and c, or if we have also Eq. (40) we can either check on our observations or get along without c or some other factor. From formulæ (40) and (41) we can find f in the terms of C′ and A, although the equation is a cubic. It is quite rapidly solved by approximation. We can then find K/c.

Then let a certain observed rate of increase of grain, represented by the slope of a certain straight line tangent to the curve of grain be s. We may not know whether it represents C or A as we have said. We shall have either

(45) $f^2 = u/u_o = E/.45\ hsc$ — from equations (43) and (41) letting s = A; or from equations (43) and (40) letting s = c

(46) $2f^2 = 1 + (E/.45\ h'sc)^{\frac{1}{2}}(2f^2)^{\frac{1}{2}}$. This equation is, however, already solved approximately in figure 6. Thus it will be comparatively easy to obtain the alternative values of v/u_o on the two hypotheses. Since $2v/u_o$ is always between 1 and 2 and the cube root varies but slowly, it will be easy to insert an approximate value in (46) and obtain nearer approximations. Moreover having found v/u_o we can go on to find K.

(47) $K = \pi Ef = \pi E\sqrt{\frac{u}{u_o}} = Cch'(2v/u_o - 1)^{\frac{1}{2}} = Ach(v/u_o)^{\frac{1}{2}}\sqrt{2}$.

It remains to be seen if K which depends on the diffusivity, the size,

the initial temperature, and a constant which represents the facility of crystallization of a particular mineral in a particular magma, will prove constant for one and the same flow as it is assumed to be for the sections from a given point.

An interesting question is where the various tangents meet—that is, where will the zone of marginal grain become equal to that of the center. If we refer to the equations of the three tangents we have the following formulæ:

$$(48)\quad x'_{13} = E \,/\, C' = ch'(2\,f^2 - 1)^{\frac{1}{2}} \,/\, \pi f,$$

where x'_{13} is the abcissa of the meeting point of the two tangents; x'_{13} / c must be less than .282 according to this formula which is the same as that represented by the full line of the figures showing the ratio E / C'c. Similarly

$$(49)\quad x'_{23} = (E - B)/A = .45\ hcf^2 - y',$$

where $(x'_{23} - y')/c$ is less than .4; and finally lines g' and g'', formulæ (40), (41), and (42) will meet at a point given by

$$(50)\quad x'_{12} = B/(C' - A) = y \Big/ \frac{h}{2\,h'}\left(1 - \frac{1}{2\,f^2}\right)^{-\frac{1}{2}} - 1.$$

From formulæ (48) and (49) we shall not be able to find the width of the contact zone, but we may often be able to if we know over what range some of these formulæ are closely applicable. If, for instance, formula (40) holds at least to a value x', it may be shown that

$$(51)\quad 2y \text{ is not less than } x'/P^{-1}\ [(u/u_0) - 1 \text{ or } 2w]$$

Also in equation (50), if we know exactly x'_{12}

$$(52)\quad y = \left(\frac{(2 \text{ to } \infty)^{\frac{1}{2}}\, h}{2\,h'} - 1\right) x'_{12} = \left(1.4 \text{ to } \infty\ \frac{h}{h'} - 1\right) x'_{12}$$

C must always be greater than A and between C' and A there is the relation

$$(53)\quad \frac{C'}{A} = \left(\frac{h\sqrt{2}\,(2 - 1/5^2)^{\frac{1}{2}}}{h'}\right)\left(\frac{C - 2y}{c - 2y - 2y'}\right)$$

up the values of $f^2 = u/u_0$ of about $.80\,\frac{h}{h'}$ is nearly 1 but as u/u_0 gets above .90 it rapidly diminishes but does not fall below $\frac{1}{\sqrt{2}}$. Thus for small contact zones

$$(54)\quad \frac{C'}{A} = \frac{\sqrt{2}}{1 \text{ to } \sqrt{2}}\left(2 - \frac{1}{f^2}\right)^{-\frac{1}{2}}$$

Again as $c - 2y = 2w$ we find $\frac{c - 2y}{c - 2y - 2y'} = \frac{2w}{2w - 2y'} = \frac{w}{w - y} = 1 \Big/ \left(1 - \frac{y'}{w}\right)$ so that if $y' = w$ $\frac{C'}{A} \doteq \infty$

$A \doteq 0$

Application of Theory of Grain to the Light House Point Dike.

We will now proceed to apply this theory numerically to a typical intrusive—the quartz diabase dike of Light House Point, Marquette,

probably genetically belonging to the Keweenawan flows; but we wish to make two preliminary comments.

First: It is likely that the margin of the dike will be somewhat cooled during the act of intrusion before the molten magma has ceased to flow, and in so far as it has done that and crystals have been formed floating during motion, we cannot expect our formulæ to apply. The irregularities will be greater in the earlier formed crystals.

In the second place microscopic examination shows that olivine is more conspicuous near the margin and intergrowths of quartz and orthoclase near the center. This suggests a chemical change and the analyses of this dike given in connection with the theory of copper deposition show that it really occurs. Apparently the olivine crystallized first and a less magnesian magma was crowded to the center. The variation of grain due to these factors remains to be seen. Initial irregularities of temperature rapidly smooth out in cooling.

Augite.

We will begin with the mineral which appears to be the latest formed of the unquestionably primary minerals, the augite. Some observations are found on pages 243 to 245 of Volume VI, Part 1, but I did not consider whether the marginal zone of increase there discussed was limited by x_{18} or x_{23}, a serious omission. The average observations on a set of sections more recently taken, on Michigan Street, Marquette, July 17, 1902, are (accuracy of measurements not over 10 per cent):

Distance.	Difference.	Grain in millimeters.	Difference.	Rate of increase.	Sx^1	B^1
0		.046				
	50		—.028	—.00056		
50		.018			.0275	—.0095
	125		.061	.000485		
175		.079			.0965	—.0175
	231		.137	.000595		
406		.216			.233	—.007
	355		.194	.000518		
761*		.410		Ave.00055	.419	—.009
	861		.259	.000303		
1622		.669				
	6608		.344	.000052		
8230		1.013				

*Augite tends to gather into chondri.

The specimens at 8,230 is from the center of the dike, so that 2w is 16,460 millimeters. The specimen at 1,622 millimeters was taken at what seemed to be the end of the zone of increasing grain, and it is obvious that if the rate of increase which holds from the margin up to 761 millimeters continued the grain of the augite would there be .9 millimeters, or nearly the same as at the center, so that the field estimate was not very far out of the way.

A second set of specimens were collected by Mr. F. E. Wright at another point not far off, where the dike is about 55.9 feet or 17,040 millimeters wide, and the contact with the Mona schist is 20 paces east

of the fence at the foot of Circle street, Marquette. We had one section which was made 5 centimeters long, to cover the 50 millimeters next to the contact. This shows that even at the margin the increase of grain is not so much greater as it would have to be if the slope we called C were A.

The result of observations on the augite at different distances are given below. It must be remembered that when the grain is very fine it is difficult to get an accurate idea of it. The average grain for the three center slides agrees well with what we found before. E is 1.07. Up to 670 millimeters the rate of increase C is .00046, which is quite as near to that previously found as we could expect, but the grain of augite at 1,890 millimeters, is certainly much finer, and that at 4,155 mm, perhaps somewhat coarser than we might normally expect. I have made repeated sets of observations on the former section, and can only account for the fineness as due to some initial irregularity of temperature or composition.

Distance.	Difference.	Grain.	Difference.	s.
0		0		
	10		.012	.0012
10		.012		
	10		.005	.0005
20		.017		
	10		.006	.0006
30		.023		
	10		.009	.0009
40		.032		
	10		.010	.0010
50		.042		
	400	.041[1]	.123	.00031
456		.165		
	166		.145	.00087
670		.310		
	1,274	.43 to .59[1]	.12	.00009
1,890		.444[1]		
	2,225	1.26	.83	.00039
4,115		1.001[1]		
	1,645	.78	−.52	
5,760		.93[1]		
	1,840	1.17	.39	
7,600		1.1[1]		

[1] Figures obtained upon revision, the second set of five sections, not quite so carefully measured. As there is none of the country rock visible in section 1, a few millimeters should perhaps be added to the distances. A further discussion of this dike will be left till later.

A third set was taken. Dr. F. E. Wright wrote Dec. 2, 1903: "Have just sent ten samples of the Light House Point diabase dike to Voigt and Hochgesang. The numbers of the specimens are 1, 10, 40, 96, 137, 170, 280, 404, 516, 670 and 740. The numbers express the distance in cm. of the specimens from the contact of the dike with the Mona schist. The specimens were taken from the same old place just east of the fence, leading off north from Arch street. You know the thickness of the dike from last year's measurements, I believe. Width —55.9 feet—17,040 mm. Not corrected for dip which is from 5°—10° to N. (measured on jointing pillars. Strike to N 75° W. The walls of the diabase are approximately parallel to the planes of schistosity of Mona schist. Dip of latter 75°—80° N.)"

One object of taking the third set was to see how far accordant results would be obtained; also the first sets did not suffice to determine A.

The results of measurements were:

Distance in mm.	Difference.	Grain.	Difference.	Ratio	
10		.01		.001	
	90		.064	.0007	
100		.074			
	300		.169	.00056	
400		.243			C'=.00061
	560		.125	.000224	B=.083
960		.368			
	410		.097	.000235	.127
1370		.465			
	330		.015	.0000454	.150
1700		.480			
	1100		.210	.000191	.081
2800[1]		.690			.048
	1240		.34	.000274	
					A=.000177
		zone of constant grain.			
4040		1.030			
	1120		—.07		
5160		.96			
	1540		+.18		
6700		1.14			
	1700		+.34		
7400		1.38			
		Average constant grain 1.13			

[1] This was misnumbered in section: I was enabled to detect the mistake by the grain.
Average gradient margin to 2,800 mm. = .000246.

The thickness of the dike is about the same in all three cases, as also the coarseness of the augite at the middle. It appears to change slowly if at all over quite a broad belt. It agrees very well with the central augite grain in Volume VI, part I, p. 244, and plate XV. We have in this later case, for a distance to the center of the dike about (23 feet) 7,000 mm. to (25 feet) 7,600 mm. dimensions of 1.0, 1, 0, 1.3, or in average 1.1 mm. Dr. Wright's specimens for one set give us 1.13 mm. and for the other set 1.07. My specimen at 80,230 mm. gives us 1.13 mm. It is plain therefore that E can hardly differ 10% from 1.10 mm.

In the Isle Royale report we had only one observation on a section close to the margin at a known distance from it, p. 244. That would give us .1 (mm.) ÷ 76.3 (3 inches = .0013).

The more recent sets both show an irregularity of increase of grain from the margin to the next adjacent section. Then the increase of grain is nearly uniform or shows no systematic tendency to vary from a uniform rate up to 761 mm. in one case, 670 mm. in the other, and 400 mm. in the third set. Though there is considerable variation in the various slides the average rate of increase or slope of the tangent is nearly the same in both. In the one it is

$$\frac{.410 - .018 = .392}{761 - 50 = 711} = .00055, \text{ in the other,}$$

$$\frac{.310 - .012 = .298}{670 - 10 = 660} = .00046, \text{ in the third}$$

$$\frac{.243 - .01 = .233}{400 - 10 = 390} = .0006.$$

These observations agree within 10% of their average and, considering that the sections are taken at different points where the dike had different thicknesses and probably not exactly the same initial temperature and pressure, as well perhaps as we could expect, and this constancy in the rate of increase rather points to its being C′ instead of A. We will, however, work out both suppositions to show the method and how we may distinguish whether it is C′ or A.

If the slope .0005 ± is C′:

Then we may find $E / C'c = 1.13 / (.0005 \pm)(17{,}040 +) = .132-$.

Accordingly by Fig. 6, following the curve of $E / C'c$ for $y = o$, (because unless we do this we ought to take $c > 17{,}040$ which would make $E / C'c$ proportionately less since $c = 17{,}040 + 2y$), $v / u_o = .77-$.

Or we may assume $\left(\frac{2v}{u_o}\right)^{\frac{1}{2}} = 1.2$ for a first approximation and solve in the equation (46).

To get some idea of y we note that apparently the grain is as coarse at 4,000 mm. as at the center but not as coarse at 2,800 mm.

Therefore by equation (49) $x'_{23} \begin{matrix} < 4{,}000 \\ > 2{,}800 \end{matrix} = .45\ h\ c\ f^2 - y'$.

Or $x'_{23} = (.293-)\ c - y'$

Also $17{,}040 = c - 2y$.

Assuming $y = y'$ as a first approximation: $2(4{,}000 - \text{a part of } 1{,}200) = (.586-)\ c - 2y'$, whence subtracting and eliminating c

$$0.414\ c = 9{,}040 + \text{part of } 1{,}200$$

$$c = 21{,}800 + \text{part of } 2{,}900$$

and $$y = \frac{21{,}800 + \text{part of } 2{,}900 - 17{,}040}{2} = 2{,}380 + \text{part of } 1{,}450$$

$y / c = c / 8$ very nearly. And if we substitute the value of c in the expression $E / C'c$ it is about 1.04 or $v / u_o =$ about .73.

But there is another way of getting the contact zone. In the third set of observations between 960 mm. and 2,800 mm. the rate of increase is fairly linear as a diagram shows and corresponds to the line $Ax' + B$.

$$A = \frac{.690 - .368}{2{,}800 - 960} = \frac{322}{1{,}840} = .000177 = \frac{1}{5{,}650}.$$

Also B will have a value between .048 and .150 more likely the larger. Thus $B / A = y' \frac{17{,}040}{17{,}040 - y'} = 850$; whence $y' = 900$.

These two values do not agree very closely but they do agree in indicating so small a contact zone that we are justified in assuming $y = y'$.

Again we have remarked that the change from the slope C′ to that of A, comes somewhere about 760 mm., between that and 400 mm. Then from equation (50) we have $y' \frac{h}{2h'}\left(1 - \frac{1}{2f^2}\right)^{\frac{1}{2}} - 1$ if $f^2 = .77 = \frac{y}{1.46}$.

Hence $y = 1.46$ (400 to 760).

This value of the contact zone is in harmony with that already found. Hence we are safe in assuming that the contact zone of appreciably affected rock of the Light House Point quartz diabase is not far from a

meter at the point in question. We then should use a value of c of 17,040 + 2(1,000) say 19,000 mm.

$E / .45\ hAc = 1.13 / (.45)(.86)(.000177)(19,000).$

$= .87$ or $v / u_o = .70.$

$E / C^1c = 1.13 / (.0005)(19,000).$

$= 1.20$ or $v / u_o = 75-.$

Or as an average $v / u_o = .72.$

Greater refinement might be gained by manipulating the data, but would hardly correspond to a real increase in accuracy.

Drawing all the observations of grain to scale in one diagram we seem to find:

For C′ .00072 and less especially for set 1.

For A .00022 and more for set 1.

For B .150 and for

$B / A = y^1 = y$ nearly 660 (mm.) and almost precisely the same for set 1.

Thus set $c = 2w + 2y = 17,040 + 1,320 = 18,360.$

$E = 1.14$ and possibly less for set (1), i. e., 1.03.

From $E / C'c = (1.14) / (.00072-)(18,360) = .87$ we have by the diagram Fig. 6, $v / u_o = .80.$

[From eq. (45) $E / .45\ h\ A\ c = v / u_o = (1.14) / (.45)(.86)(00022)(1,836)$ we have $v / u_o = 74.$

We will therefore assume these values as the most likely: $v / u_o = .72$, $y = y_1 = 660$, but we know that the ratio v / u_o may be ± .02 out.

According to this supposition, then, the augite, latest formed of the minerals crystallized from the magma, had hardly formed at all when the magma came to rest,—not over a very few mm. from the contact. It was formed at an average temperature about three times as near the initial temperature of the magma as that of the country rock. So that if the temperature of the country rock was about 40° C. and that of the formation of the augite 1,090° C. the initial temperature of the magma would be 1,440°. Moreover there would be a contact zone appreciably warmed on each side of about a meter.

This is undoubtedly the correct supposition. For if we assume that this slope of .0005 to 7, instead of representing C′, represents A, multiplying it by (x′), the distance of the various sections from the margin, and subtracting it from the grain we ought to get B, and the B/A would by Eq. (44) give us (y) the contact zone. But as a matter of fact if we take the slope from 50 mm. to 761 mm. or 60 mm. to 670 mm. we get as in the last column on p. 226, negative values of B, and hence impossible values of the contact zone, except in one case. And even if we suppose we assume the slope taken for A to be very slightly in error, though we can find slopes within 10% which will not give us negative values of B, they will still be *very small* and the contact zone accordingly also exceedingly small. Practically we shall have to suppose that owing to the wetness and convection of the country rock or some other cause the country rock was kept at a nearly constant temperature. This is the

erroneous supposition I made in the Isle Royale report. But in that case v/u_o would be by Eq. (45)

$$\frac{v}{u_o} = f^2 = \frac{E}{.45\, h\, Ac} = \frac{1.13}{(.45)\,(.88)\,(.0005)\,(17{,}040+)} = .300$$

I got a similar value in the Isle Royale report, simply by observing the curve. If the country rock temperature was 30° C. and the augite formation temperature was 1,090° the initial temperature would have to be 3,350° C. We should have to assume a very much hotter magma initially and get at the same time practically no contact zone, a much less likely state of affairs. Not only this but the rate of increase .0005 should continue practically up to[1] 1,622 mm and beyond, which it evidently does not. So we have here a direct argumeut that the marginal rate of increase of grain can not be A. We have therefore the cumulative effect of an improbably large error in determining the rate of increase, and an improbably high temperature, especially as coupled with an improbably insignificant contact zone against assuming that the rate of increase .0005 represents the slope A rather than C′.

Moreover if it is C′ other minerals formed before and at a higher temperature would be much more liable to be formed in the earlier stages of cooling, or even before flowage ceased than in the latter case. We shall proceed then to discuss the observations on them, taking them in the inverse order of solidification, and shall find that they show distinct indications of having been formed in an earlier and very early stage of the cooling.

Magnetite.

The magnetite is in part at least formed after this labradorite, laths of which penetrate it[2] in the sections taken in 1,890, 4,115, and 7,600 mm. Furthermore there is almost no sign of a porphyritic texture with flow crystals which the feldspar has. It, however, distinctly and sharply precedes the augite formation. The rate of increase close to the margin is certainly between .0008 and .0003, and apparently very close to .00036. At the center, however, comparing the observations in the Isle Royale report and our sections it seems as if values differed greatly. For one thing we can not distinguish aggregates and it also seems as if there may have been some absorption.

The intermediate observations vary quite largely as to the intermediate grain, but it is notable that they point to a $y=y'$ of from 600 to 1,500 mm. Thus it will be safe to assume the same width of contact zone and c as for the augite. The value of A lies between .000117 and .00017.

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[1] If $x'=1622$, $m=\frac{x'}{c}\, m_o=.095m_o$, and $24\frac{x'}{c}$ has a value between 2 and 3 of table I and if $u/u_o=.315$ it is easy to see from that table that the value of g will be close to .80 and of m_o close to 3.34. That implies that $u\text{-}u_o$ is nearly equal to P_m, i. e., by table II, that is, near .29 which implies that $m_o=3.05$ but for any such value of m and m_o h is practically invariable. $x'=.88$ and $g'=Ax'=.8$, or in other words the linear increase of the grain should continue up to 1,622 and beyond.

[2] In working up the grain observations I forgot this fact, which I had noted not only in these slides but also in the Isle Royale report p 246, and started in on the hypothesis that it was older than the feldspar. The curves of grain quickly apprized me of my error.

From $E/C'c=.78+/(.000365+)$ (18360) we obtain

$E/C'c= 1{\cdot}16$ a greater value than for augite, i. e., $v/u_o=.75$.

From the equation (45)—

$v/u_o=E/.45\ h'\ A\ c=.78+/.383$ (.000117 to .00017) 18,360 we see that to have a value of v/u_o as low as augite, if $E=.78+$ A must be .00022+, so that v/u_o is pretty surely greater than for augite. If $v/u_o=.75$ A=.0002.

The indications are therefore that the magnetite is formed at a temperature $v=.765\ u_o$ or greater. Taking E larger will increase v/u_o rapidly. It seems quite possible that the contact zone and grain may vary at different parts.

Very possibly the more or less ready absorption or diffusion of the gases of the magma into the country rock and consequent oxidation was a determining factor. It seems to me likely that with the loss of temperature and mineralizers and the crystallization of labradorite, when the time came that the olivine already formed was corroded (as microscopic examination shows it was) absorbing silica and turning into the augite molecule, there was a release of some of the Fe–O– which, absorbing a little O from the H–O–, allowed that to become H–O–H or water and became itself magnetite Fe_3O_4. This is a good illustration of the fact that v and u_o of our expression do not stand for heat merely but for that and any other conditions of crystallization that follow similar laws of diffusion.

GRAIN OF MAGNETITE OF QUARTZ DIABASE DIKE, LIGHT HOUSE POINT, MARQUETTE.

Observations on set (1).

1 Distance from margin.	2 Difference.	3 Grain in mm.	4 Difference	5 4 ÷ 3 quotient 3
		.005		
0		.01±		
	50			
50		.002 dust		
	125		.008	.00055
175		.07		
			.061	.0002
	231	.131		
406		.064 to	.15	.00042
	355	.092[2]	.17 to	.00048
		.28	.143	.0004
761		.235	.129	.00015
	861	.269	.280	.000326
1622		.515	.56	.00006
	6608	.93[1]	.40	.00006
8230		.92[2]		

Observations on set (2).

0		.0		
	10			
10		.0	.02	.0007+
	10			
20				
	10			
30		.02		
	10		.01	.001
40		.03		
	10		.01	.001
50		.04		
	400		.09	.00022
450		.13		
	220		.11	.0005
670		.24		
	1220		.34	.0003
1890		.58		
	2225		.38	.0002
4115		.96		
	1645		.04	.00001
5760		1.00		
	1840		.46	.0002+
7600		1.46		

[1] Upper numbers obs. October 31, on Kuntz's sections.
[2] December 24.
[3] One extra large porphyritic grain.

Observations on set (3) in mm.

Distance.	Grain.
10	? (dust)
100	.02 (dust)
400	.128
960	.238
1370	.209
1700	.335
2800	.437
4040	.454
5160	.53
6700	.65
7400	.78

Grain of Labradorite in Lighthouse Point Quartz Diabase.

The feldspar at the extreme margin is more slender and trichitic than when it is coarser and that complicates the measurement of the grain. Near the margin these feldspars show flow arrangement and lines of coarser and finer. At 50 mm. there is a distinctly porphyritic texture and even at 175 mm. and 450 mm. and 616 there is a quasi-porphyritic

texture there being a good deal of range in the size of the feldspars, many large but some quite small. Farther in the porphyritic appearance disappears. This plainly indicates that at the time of cessation of motion the temperature had dropped so much for a belt at least 7 and 16 inches wide from the margin that feldspar formation had begun. This being a broader belt than for the augite a temperature and time of formation of feldspar in advance of the augite is indicated, and we shall expect to find more evidence of initial irregularities of temperature in the feldspar grain. This we do as appears from the observations. It is more difficult to measure the grain of the feldspar owing to its pronounced tabular shape, and the fact that at the margin the latter seem to arrange themselves parallel to the walls. This may be due merely to the flow and pressure but I strongly suspect that it is a thermal phenomenon.

The method of determining the grain, which is fairly successful for the augite and magnetite fails entirely for the feldspar for it is entirely impossible to exclude the rhyocrystals (or crystals formed while the magma) was still in motion from those formed after it came to rest. Moreover their presence as crystallization centers (German "Impfen", buds or grafts) would tend to produce a finer grain, by interference. At a general look it seems quite plain that the feldspar is coarser at 7,400 mm. than at 6,700 mm., but I have been able to devise no system of measurements to put this into clear mathematical and tangible shape. As a matter of fact, the feldspar began forming among the very earliest constituents, even before the magnetite and olivine. But there are indications that it continued growing while the augite was forming, even though as far as the M (010) face is concerned it is idiomorphic against it. Where the feldspar is imbedded in a patch of augite composed of one or more individuals it is often noticeable that the feldspar laths near the center of the patch are smaller than those in the margin or grouped by themselves outside.

In fact not only did the feldspar continue to grow during the formation of the augite but, changing in composition and inter-grown with quartz, it fills the last interstices. In this case, however, it is apparently orthoclase, and there appears to be a rather sharp line between that and the previous soda lime feldspar.

It is thus indicated that the conditions of formation of the feldspar are very largely chemical.

A few of the porphyritic laths of feldspar are as long at the margin as at the center but the average length is certainly much greater, and they are also broader in proportion. Near the margin the rate of increase C′ for the smaller crystals, not formed while in motion is not less than .00075 in any case.

Then C′c will be say 20,000 mm. x .00075=15 mm. E is for these surely not greater than 1.65 x .34=.56 mm. for some of the porphyritic feldspar formed in motion might be mixed (or $\frac{\sqrt{50 \text{ to } 55} \times 18}{53}$) from

third set of observations). This would give for E / C'c a value of .038, so low as to point to consolidation immediately at the temperature of the margin, which is not in harmony with what we have said.[1]

LABRADORITE.—FIRST SET.

No.	Distance.	Difference.	Grain in mm.	Difference.	Quotient.
1	0		.0131		
		50	.49×	{ .0093 { −.65	.00019 −.013
	50		.0224		
		125	.425×	{ −.007 { .22×	−.00005 .00191×.3
2	175		.0152		
		231	.64×	{ .330 { .21×(.3)	(.0008) to 406 ave. .0010
5	406		{ .334 { .345		.001×.3=.0003
			.85×	{ .094	.000264
		355	1.28 to 1.48× $\sqrt{.1}$	{ .060 { .26×(.3)	.00014 .00073×.3=.00021
			{ .428	{ .214	.000248
3	761		{ .395	{ .395	.000218
			{ 1.11×	{ .08×(.3)	.0001×.3=.00003
		861	{ .643[1]		
			{ .79[2]	{ .025	.000004
			{ 1.19×[3]	{ −.236	−.00004
4	1622		{ 1.64× $\sqrt{.1}$[4]	{ .67×3	.0001×.3=.00003
		6608			
			{ .667		
12	8230		{ .554		
			{ 1.87×		
			{ 1.7 to 2.15×$\sqrt{.1}$		

[1]Observations of Ohm sections, Jan. 13.
[2]Observations of Wright sections, Oct 31.
[3]Observations of Wright sections, Oct.
[4]Observations of Ohm's sections, Dec. 24.

The lower two sets are rough incomplete observations.

The magma appears to have secreted first a little magnesia silicate (olivine). Then as the temperature dropped there seems to have been no tendency to separate any lime salt etc., until it could crystallize out say the Labradorite $Ab_2 An_3 = 2 (Na_2 O\ Al_2 O_3\ 6\ SiO_2)+3\ (2\ CaO,\ 2\ Al_2 O_3\ 4\ SiO_2)$ which has the ratio $Na_2O : SiO_2 :: 1 : 12$. Beginning with this the amount of soda gradually increased as the variation in extinction shows. The augite may have begun to crystallize when the ratio of Ab : An in the Labradorite was $Ab_2 : An_1$ for that has the same ratio of bases to SiO_2 as augite. Thenceforward the augite and the labradorite may have grown pari passu as a eutectic mixture as above noted, until the lime was practically exhausted. Previously, however, a certain amount of iron (which may at high temperatures have been ferrous iron Fe–O– having perhaps taken O from H–O) crystallized as magnetite.

After the crystallization of the augite and labradorite the remainder was probably capable of undergoing a considerable drop without crystallizing, being probably a hydrous solution of silica, potash and alumina, calcium and other chlorides.

[1] While this is in press, I have seen Day's paper on the fusibility of the feldspars. The higher temperature of formations which he finds for the feldspars and their tendency to undercooling fit in very well and explain much that had puzzled me.

The olivine which very early crystallized out, yet only in very small porphyritic crystals at the margin, did therefore not begin to crystallize much if any before the dike came into position. This inference agrees with the facts: first that the grain varies from center to margin: second that the marginal crystals are not corroded while the central are: third with the fact that Barus found the temperature of thorough liquidity or fluidity of a very similar diabase to be 1,360°; and fourth with the fact that the curve of grain of the augite indicates that the initial temperature of the magma was some 1,400° or a little above that of fusion of olivine as we have already mentioned. Observations on the grain of olivine indicate, therefore, much less.

Grain of Mt. Bohemia Gabbro-aplites.

It will be remembered I stated that Mr. F. E. Wright, the Assistant State Geologist, is studying the Mt. Bohemia gabbro. Its composition is much like that of the Duluth gabbro described by Winchell and U. S. Grant as will be seen by comparison of analyses. In it there occur seams or aplite veins and it itself sends out aplitic seams of the red rock into the contact zone of altered ophites. These rocks are mentioned in Volume VI, part 2, pp. 72–73, and the presence of these red stringers from the gabbro in the contact zones confirms the conclusions I drew there as to the intrusive character of the gabbro. They are formed only a few feet from the gabbro in the contact zone, and correspond to the red rock described by U. S. Grant and Bayley, and by Irving.

They are only a few mm. thick but they are uniform in grain from side to side and while fine grained as will appear by no means aphanitic. The fact that they are crystalline though so small and that the grain is uniform indicates (comparing curve 40 of Fig. 5) that the country rock was hot at the time of their injection. Of course the country rock may have been heating first and cooling later as the result of the injection of the gabbro as a whole. But the average effect on the grain is as though the temperature of consolidation was considerably nearer that of the country rock than the initial temperature of the magma, and that we see agrees nicely with the field conditions. The grain is then wholly determined by the formula for $E=\frac{kc}{\pi a\sqrt{u}}$ and u represents the difference between the country rock and the consolidation temperature. As c is small u must also be relatively small that E may have much value. E, the grain should also depend on c, which we may assume to be proportional to the breadth of the little dike. As we see from the table of the sections below, which gives the average length of the rectangles of orthoclase and the breadth of the dike, such is the case.

Letter of specimen.	Breadth.	Average dimensions of feldspar.	Calculated.
B	10 mm.	0.305	.324
E	14	0.486	.455
D	22	.73	.71
C	31	1.23	1.01
H	32	.89	1.04

We see that the grain does appear to vary quite directly with the size of these feeders. The observations on the grain check with the field observations and distribution and close welded contacts in proclaiming these either contemporaneous with or closely subsequent to the main intrusion.

THE THEORY OF COPPER DEPOSITION.

ALFRED C. LANE, STATE GEOLOGIST.

During the past few years there has been a lively interest in the theory of the origin of ore deposits, and recently two works have been published by the Institute of Mining Engineers and by the *Engineering and Mining Journal,* which give a very good account of the present state of the controversy, and references enough to start one pretty well over the whole field of the latter.[1] In these discussions our deposits of iron ore and copper of Lake Superior have been frequently used as illustrations of the various theories by those who take part in the discussion. In view of these facts, it seems proper to give a review of what is known concerning the copper of Lake Superior and of the theories regarding the same with reference to recent developments. There is also a practical interest involved in the discussion. As we shall shortly see, all the best authorities at present agree that the copper has been deposited by water, but there is some difference of opinion as to whether the water current is a descending one and the copper was deposited and a circulation produced by gravity, or ascending, and the circulation due to one or more principal causes, which we may call, as a common name, volcanic, meaning thereby, that they are connected with the interior heat of the earth. Now, it is a common notion among the practical Cornish miners of the copper country, although I do not remember to have seen the statement in print, that the copper is liable to occur under high ground.

To understand what is meant by the expression "high ground," we must remember that at the present day the bulk of the copper is deposited in bedded lodes. It would be perhaps more correct to say that it comes from lodes whose strike is the same as that of the beds of the Keweenaw formation. It is commonly accumulated in the originally more porous parts of these beds. Sometimes these porous parts are sandstones and conglomerates, but more often they are the porous upper parts of lava flows. It is, I believe, true that in many cases there are faults parallel to the bedding planes, or so nearly so that the difference has not been detected, which have had an important influence on the production of copper. In some

[1]Genesis of ore deposits. Reprinted papers from Volumes XXIII, XXIV, XXX and XXXI of the Transactions of the American Institute of Mining Engineers. Published by the Institute at the office of the Secretary, New York, 1902.

Ore Deposits, a discussion republished from the *Engineering and Mining Journal*, New York, 1903.

See also Geological Survey of Michigan, Vol. I, Part II, p. 43. Vol. VI, Part I, p. 216.

Yet more recent: Trans. Am. Inst. Min. Eng., October, 1902. Igneous Rocks and Circulating Waters as Factors in Ore Deposition, by J. F. Kemp; Ore Deposits near Igneous Contacts, by W. H. Weed, and discussion of same. Annual Report of the State Geologist (of New Jersey), 1902. Copper Deposits of New Jersey, by William Harvey Weed. The Chemistry of Ore Deposition, by Walter P. Jenney.

cases we know there are such faults, which generally have a somewhat steeper dip than that of dips generally.[1]

Nevertheless, in a practical way, the most characteristic feature of these lodes is the porous beds. Any one of these porous beds may contain copper, and there are few of them, which are decomposed, that do not show some trace of copper. But the parts which are relatively rich, rich enough to be the sole object of interest to the miner, are rare, and the meaning of the idea that copper occurs along high ground is, as I understand it, that in following the outcrop of such lode, chutes of copper are liable to occur where the outcrop of the lode is extra high. Now, there is some ground for this idea. If we take the Baltic lode, just developed, we find that in the Baltic, Trimountain and Champion mines, this is rich, while just northeast, on section 16,[2] the Atlantic mine has done a good deal of exploring without being able to find the lode because the lode when encountered was not rich. Rising once more on the high land, we find the Isle Royale mine close to the deep trough of Portage Lake, where, on the other side, is the Quincy mine, on high land again. The Sheldon and Columbia and Hancock mines, more down in the Portage Lake valley, do not appear to have been so successful. Going farther north, we find the Calumet & Hecla, Tamarack, Kearsarge and Wolverine mines, not very far from the Allouez gap on the southwestern side; on the northeastern side is the Mohawk mine. Nearer the gap is the Ahmeek property, which is just being opened up and whose true value has not been determined. If the "high ground" notion has any substantial basis, its prospects would not be so good as those of the Mohawk and Wolverine mines,[3] although it lies on the same lode and between them. The Phœnix mine and the Cliff lie on higher land, not far from the gap of Eagle river, and turning to the other end of the range we find the Minnesota and the National on one side and the Victoria on the other of the gap made by the Ontonagon river, while the Mass and Adventure lie on the high land between the Flint and the Fire Steel rivers.

Now, this grouping of mines in accordance with this notion that the copper occurs on the high ground may be due to the fact that the porous beds are usually covered by drift, and therefore, not exposed, and not easily exploited or developed, except on high ground. It might also be suggested that the alterations which produce the copper has cemented these beds more firmly and had thus given a greater resistance to erosion, either by ice or water. The copper itself, however, even in the richest mines, is only a small fraction of the rock, and is easily decomposed chemically, and so are some of the associated minerals, and, although at times, copper bearing amygdaloids, as the igneous porous beds are called, are more or less saturated with silica and epidote, I do not think those minerals are so characteristic of the copper-bearing lodes as to lead to a

[1]The top of the Calumet and Hecla is markedly slickensided. See also Volume VI, Part II, pp. 86-94; the slide fault in the Central mine appears to be nearly parallel to the Kearsarge conglomerate. The accumulation of copper was in the vein above this slide, and on reaching the conglomerate they worked on top of it finding good copper ground.

The annual report of the Phœnix mine for 1901 shows in the section by Dunbar D. Scott, the steeper fault slide in that mine, in the St. Clair vein. The old Minnesota, now Michigan mine, had its largest deposit of copper where a steeper fissure intersected a lode. See report Commissioner of Mineral Statistics for 1880, p. 76. Copper Handbook, 1902, p. 195.

See also Van Hise, Iron Ore Deposits of the Lake Superior Region, pp. 344-348, for account of the same system on the Gogebic Range.

[2]Vol. VI, Part II.

[3]Per contra the good rock obtained at the Ahmeek, and as Agent Denton informs me in the south end of the Winona under the swamp, is against this idea.

relatively greater elevation of such parts of the lode. However, there is room here for inquiry.

I leave to the last another possible explanation which has a more direct connection with the theory of the deposition of the copper. If the copper is deposited by descending waters, as Pumpelly, who has done by far the most work upon the subject, suggested,[1] and the motion of these descending waters is determined by gravity, descending along the lodes at one branch of the inverted siphon and rising either in the same lode at a lower point of its outcrop, or in some cross fissure, which might very well be the cause of the gap in the range, then we can readily see that the greatest activity of circulation and the greatest deposition of the copper consequently, should be beneath salient points of the outcrop of the lode. Take for instance, the Calumet & Hecla. That deposit outcrops 600 or 700 feet above Lake Superior, and the chute of the richer streaks in the deposit is northward, and we may imagine the waters working down in that direction to reappear over in the Allouez gap or up some fissure which may possibly have determined the gap. We see, therefore, that the question as to whether the copper was deposited by waters circulating in one fashion or another has a practical interest in guiding the search for the richest parts of the lode. Van Hise has suggested not only this, but that the richer parts of the lode—called chutes—will be found beneath upward bends if the waters of deposition are ascending, beneath downward bends if the waters of deposition are descending. If he is right, which I doubt, in saying that the copper of the Michigan lodes are deposited by ascending waters, the southern end of the Ahmeek and the northern part of the Kearsarge properties is more likely to be extra productive according to Hubbard's map of the Allouez gap area (Volume VI., Part II., Plate VII.), but if the waters are descending, the same area is more likely to be lean.

In the first place, we may premise that it is a settled question that the copper was deposited by water. All kinds of authority agree in this, although at one time a few geologists thought of its being inserted in a molten state. But native copper and native silver occur together, as they could not if they were melted. They would at once be alloyed. Jewelry is often made of sections of nuggets of copper and silver, popularly known as halfbreeds, where the sharp and irregular line between the copper and silver is beautifully displayed. We also find copper grown upon minerals, like analcite and prehnite, which one can fuse in a candle flame. It is not very rare to find a sharp crystal of dog-tooth spar entirely plated over with copper, and then the growth taken up again.[2] Pumpelly has given in Volume I. of our reports, a most thorough discussion of the way in which the copper occurs.

It is worth noting that most of the Michigan geologists from Douglass Houghton down, have recognized that the copper was intimately associated with the traps in its origin, and that Dr. Wadsworth agrees with Foster and Whitney, Mueller and Pumpelly, in attributing the deposition of the copper to descending waters.

In the "Notes on the Geology of the Iron and Copper Districts of Lake Superior," which he issued in 1880,[3] he says:—

[1] Vol. I of these reports, Part II, p. 40.
[2] See Volume I, Part II, Chapter 3; also Volume VI, Part II, pp. 163 to 165 of our reports.
[3] Bulletin of the Museum of Comparative Zoology, Vol. VII, No. 1, pp. 86 to 130. See especially the resumé on p. 109.

"Whatever may be our view respecting the sources of the copper, it is evident that it was deposited by aqueous agencies, and that the general course of the solution was downward," p. 110, and again on page 123, he refers to the decomposition brought about by the medium of the "percolating waters, whose course seems, in many cases at least to have been downwards." On page 126 he writes, "The copper has been found throughout the district underlying heavy beds of trap or a series of smaller ones; in fact, in the parts visited by us, experience has shown that copper in abundance was only found where trap in large amounts overlaid the vein or bed" [this would not apply to the Nonesuch]. "The copper was found filling, at the Calumet and Hecla mine, the joints of the overlying trap, and extending as a continuous sheet through fissures at right angles to one another. At Copper Falls spikes of copper extend downward out of the overhanging trap into the ashbed. These are generally large at the upper and pointed at the lower end. Like them are the secondary depositions of calcite, in this trap, in long spike-like forms, that here and elsewhere have been taken for fossils. These features prove that the copper comes from fossils above downward,[1] and that it was deposited after the jointing of the trap."

A very interesting specimen, owned by Dr. Hubbard, shows a crystal of quartz which has been corroded and mainly replaced by native copper. Moreover, in the deeper part of the Quincy mines, Dr. Koenig has found a water which is now depositing copper and contains 9 grams to the metric ton of the same, and Mr. Geo. L. Heath, chemist of the Calumet and Hecla has also found copper in their mine water (p. 166).

I have shown in my United States Geological Survey water supply paper No. 31, on the different waters of Lower Michigan, that while each porous bed varies in the character of water from point to point, yet there is little intercommunication between them and it is difficult to see how there could be much, except upward along fissures or drill holes. Beds of clay or shale are known to be so impervious to water and to oil, they may be taken to be, even in a geological sense, impervious layers, permanently guiding and separating the different flows of water. The same statement applies to clayey belts of decomposed rock, paint rock and fluccan, as Van Hise himself has pointed out in ably discussing chutes and formation of the Galena lead deposits. Thus, it must be remembered, that Van Hise's figures of underground flow apply only to a homogeneous medium. His figure 5, for instance, might represent the flow of water in one single porous bed, say of conglomerate, sandstone, or amygdaloid, but not the formation at random. It is by no means practically true, therefore, that the zone of fracture "will be searched to its base by moving waters," unless beside being not only potentially but really fractured, so as to make it practically pervious as a whole, it is also covered by a surface topography so rough as to stimulate circulation. These two conditions will be best fulfilled in those mountainous districts, which, as Van Hise remarks, are most liable to contain ore deposits, page 416.

Now, the difficulty in supposing that the copper deposits are due to such a general circulation of water taken in at the surface, as Van Hise imagines, is very great. The following is a sample of water from the

[1] Smyth and Van Hise are the only prominent geologists who look for the origin of the copper outside the formation. The association of copper with traps in New Jersey and elsewhere points to a genetic connection.

Arcadian shaft, a relatively shallow shaft, analyzed by Dr. Koenig, August 23, 1898:

	Grams per ton.
$CaCO_3$	32.7
Fe_2O_3	13.7
Kaolin	100.0
$FeCO_3$	24.5
$MgCO_3$	25.6
$MgSO_4$	60.2
K_2CO_3	10.9
Na_2SiO_3	101.3
NaCl	trace
$Na_3P_2O_5$	2.2
Na_2CO_3	42.3
Organic matter, $C_{50}H_{54}O_{27}$	8.2
Total	421.6

Elsewhere in this report a number of similar analyses are given. The specific gravity is practically 1.000.

On the other hand a deep mine water coming in at the 46th level of the Quincy, was analyzed by Dr. Koenig, with the following result:

Sp. gr.	1.1898
$CaCl_2$	17.91
NaCl	2.96
$MgCl_2$	
SO_3	0
Iron	0.004
Copper	0.009
CO_2	0.00

Now these two analyses are typical.

Analyses at Freda and in the Hecla mine, given above, indicate a similar deep water. It will require considerable head to counterbalance such a difference of gravity.

The deep waters are strong solutions of earthy chlorides. A water with nearly 1 per cent. of bromine oozes in the 45th level of the Tamarack. The shallow waters are high in alkalies, and so low in chlorine that the alkalies have to be combined with other acids. It is no wonder that, as Pumpelly remarks, alkaline zeolites occur in the upper levels. One might explain the loss of carbonates if the upper water was descending by a precipitation of the same, such as we know has taken place, but I do not see that we can so explain the presence and absence of chlorine. That must, it seems to me, have been an original constituent of the deeper rock moisture, either from the sea in which the rocks were laid down, or of the igneous magma. Prof. Moore in his presidential address before the Liverpool Geological Society (1903, p. 269) has shown that at the top of a 96 foot thick intrusive sheet there is a 10 to 15 foot belt, corresponding to the amygdaloids of the Keweenawan series, which contains a little over 4 per cent. carbonic oxide and 2.6 per cent. water which are, as he believes, probably primary, although now combined as ferro-dolomite.

Moreover, around volcanic centers the escape of vapors containing chlorine and carbonic oxide and the formation of crusts of iron chlorides are common.

Now, if they escape they must be present in proportion to their vapor pressure in the lava and can hardly wholly escape, but must be present more or less, in the rock moisture of the acid interstices which I have so fully described for the intrusive rocks. But even in an effusive as the rock above figured, we see that between the crystal of augite and that of feldspar, each having its own shape, is an angular space which must have been a pore originally, filled probably with gas. In a thoroughly crystallized trap, doloritic melaphyre or diabase, like that of Lighthouse

ANALYSES OF STONE FROM LIGHTHOUSE POINT,

Under direction of E. D. Campbell, by E. E. Ware, June 30, 1903.

Distance from margin.	Contact.		616 mm. 2.2 ft.		4,115 mm. 13.5 ft.		7,600 mm. 24.9 ft.	
	No. 1.	Molecule.	No. 3.	Molecule.	No. 6.	Molecule.	No. 8.	Molecule.
SiO_2	46.98	.783	47.67	.795	47.25	.787	47.10	.785
Al_2O_3	17.85	.175	17.55	.172	18.00	.176	17.47	.172
Fe_2O_3	3.13	.019	2.51	.016	2.21	.014	2.66	.017
FeO	10.30	.143	12.59	.175	12.42	.172	12.93	.179
MgO	(a) 7.10	.177	5.65	.141	6.35	.159	6.88	.172
CaO	(a) 8.47	.152	10.75	.192	11.45	.204	10.27	.183
Sodium oxide	2.04	.033	2.21	.035	1.96	.031	1.91	.031
Potassium oxide	.60	.006	.65	.007	.66	.007	.59	.006
H_2O at above 800° C	(b) 1.97	.168	.35	.112				
H_2O at 110° C	(a) 1.55	.036	.40	.028				
CO_2	.20	.005	.18	.004				
P_2O_5	.143	.001	.169	.001	.158	.001	.161	.001
S	.097	.003	.183	.0057	.086	.0027	.111	.003
Cl	.07	.002	.05	.0014	.02	.0006	.09	.0025
MnO	.26	.003	.19	.003	.18	.003	.15	.002
	100.700		101.102		100.744		100.322	
Ratio, alkalies: SiO_2	.048		.053		.0483		.0472	
Ratio, pore space: solid space, in gasolene	.0473		.0012		.0032		.0013	
In water	.0429		.0008		.0028		.0015	
Sp. Gr. in gasolene	2.83		3.02		3.01		3.02	
In water	2.89		3.06		3.05		3.07	

(a) Checked later in another sample.
(b) Determined on new sample, first method incorrect.

Point, whose analysis and porosity we give, the porosity is not over 1 per cent. But in the case of an amygdaloid the original amount of vesicular space may have been very considerable, and this space must have been filled either with the original gases or possibly in the case of submarine flows with sea water more or less contaminated with such

gases. Such an origin would readily account for the saline character of the waters, and it is worth noting that such saline waters attack copper, as is shown by the fixtures around the salt baths of Lower Michigan.

Pumpelly furthermore concludes that the water which deposited the copper was descending. One of the arguments which he used is that the alkaline silicates abound in the upper levels and are (page 40) rare in depth; "in other words, they are abundant in that zone of the veins which lies between walls of those portions of the beds of the melaphyre in which we should look for the most advanced stages of alteration in the components of melaphyre, supposing such alteration to be due to the action of descending solution." By alkaline silicates he means analcite, apophyllite, orthoclase (and datolite of the same age). Copper occurs of similar

Fig. 7. Illustrates original cavities, in a rock of the copper bearing series such as may have been originally filled with chlorine gases, as at a, wedged in between feldspar laths and an octagonal augite grain.

age in some of these deposits. In studying the alteration of the lava flows which form so large a proportion of the Keweenawan series, I find that the olivine is first to alter, then the augite, and lastly the feldspar.

There are other arguments, like those mentioned by Wadsworth, which may be used to support this theory with regard to the origin of copper. I wish also to add a few new considerations. As has been said, down to say 500 or 600 feet, the water of the mines is quite fresh. In the deeper mines, while there is very little water, it is an extremely strong solution of chlorides. The line between the two classes of water is reported to be very sharp, and there is a chance for a very interesting investigation right here. It would seem quite difficult to suppose a circulation of this heavy water up into a light fresh water, especially under high ground, and to imagine that there could be a sharp line between

them. One would expect to find brackish waters clear to the surface, and that even if the heavy waters rising were diluted by affluents, they would retain the same general character, whereas the surface waters and the deep waters are chemically entirely different. If there was a tendency for the waters to descend, however, the rocks might naturally draw in fresh water of entirely different character from the outcrop.

Van Hise might, however, suggest that the present distribution of waters is a recent phenomenon, the present circulation being indeed downward, but much later than the origin of the copper.

We may also suggest another factor which might stimulate the circulation of water. We have mentioned the fact that there has been faulting. Now, if by faulting, the upper light sodium silicate water is brought on one side of the fault plane, and the heavier earthy chloride water on the other, there would surely be circulation, and precipitation, too, unless the fault plane were coated with a very perfect impervious sheet of clay flucan.

Suppose, for illustration's sake, a sliding of the upper beds down, such as that suggested by Hubbard at the Central mine,[1] relatively light, and superficial waters would be brought above the deep waters and the heavy earthy chloride waters would tend to work up through the fault plane, depositing as they went. If, on the other hand, the fault was a reversed fault, the reverse phenomenon would take place.

Another most weighty argument is the occurrence of copper native in the iron ores near Crystal Falls.[2] One can hardly imagine this other than produced by descending waters, since the iron ore is universally allowed to have been formed by descending waters. Moreover, it occurs in the upper parts of iron ore bodies and is not known to have any connection with lower deposits. It may easily be conceived to have been derived from an over-lying extension of the Keweenawan, now eroded away.

Pumpelly supposed that the copper may have been originally deposited with the strata, as sulphurets under submarine conditions. He was slightly inclined to call the old lavas altered (metamorphic) sediments.

Irving apparently agreed with Pumpelly[3] and Wadsworth, speaking of the copper having been arrested in its descent. More recent writers on ore deposits, however, differ from the Michigan Geological Survey and seem inclined to refer the origin of the copper deposits to the upward rising waters. For instance, Posepny writes as follows[4]:—

"Some of the attempted explanations assume, in my opinion correctly, as the cause of the first ore depositions, the action of hot springs—in which connection it is only to be emphasized that these thermal effects occurred long after the intrusion of the eruptive flows between the sedimentary strata, so the ores were brought, not by or in the eruptives themselves, but by the later springs, from great depths and perhaps from considerable distances. This explanation, applicable to all deposits, suits also the exceptional case cited by R. D. Irving, namely, the Nonesuch copper bed in the sandstone of Porcupine mountain, far from an eruptive outflow." Posepny seems to have been influenced in the first place by a strong prepossession as to the role of ascending solutions, and in the

[1] Vol. VI, Part II, p. 91.
[2] Prof. A. E. Seaman writes that he has native copper in iron ores from the Cliff mine at Iron Mountain, also with ferruginous chert from the tenth level of the Great Western mine, Crystal Falls, also from the Montana mine, Tower, Minn., where it occurs in the iron ore.
[3] Copper-bearing Rocks, pp. 426, 427.
[4] Page 145.

second place by the occurrence of the ore as a mineral or rarely sulfide and not as carbonate. The connection of the copper with the Keweenawan trap formation is much too close to be ignored, and, in fact, widely in the world native copper and traps (hessoses) are associated, as recently described by Weed in New Jersey. The Nonesuch bed is dark and very largely made up of basic trap fragments.

Prof. Van Hise, in his very interesting article on "Some Principles Controlling the Deposition of Ores," uses our metallic copper deposits as a conspicuous illustration of ore deposits where the concentration by ascending waters has been sufficient without secondary concentration by descending waters, writing as follows:—

"In some cases the deposits thus produced are sufficiently rich, so that they are of economic importance. In these cases, which undoubtedly exist, but which perhaps are less numerous than one might at first think, a concentration of ascending waters has been sufficient."

"A conspicuous illustration of ore deposits of this class which may be mentioned are the metallic copper deposits of the Lake Superior region. The copper was in all probability reduced and precipitated directly as metallic copper from upward moving cupriferous solutions. The reducing agents were the ferrous compounds in the solid form, in part as magnetite and as solutions derived from the iron bearing silicates. When the copper was precipitated, the iron was changed into the ferric condition. It is well known that metallic copper once formed is but slowly affected by the oxidizing action. Oxidation has, in fact, occurred in the Lake Superior region, but from the facts now to be observed, not to an important extent. An oxidized belt may have formed in pre-glacial times, but if so, it was swept away by glacial erosion, and sufficient time has not yet elapsed to form another. The ore deposits now worked have apparently remained practically unchanged since the time of their concentration. In this fact we have the explanation of the great richness of these deposits to extraordinary depths[1]."

Prof. H. L. Smyth, of Harvard, had also adopted the same belief and I have already discussed it in Vol. VI. of our reports. Prof. Smyth believes that the various flows were surface weathered and the earlier non-alkaline minerals produced thereby. The later alkaline minerals he believes to have been associated with the northerly and northwesterly tilting, and the formation and the filling of the fissures and the impregnation and partial replacement of amygdaloids and conglomerates with copper, the copper not being derived from overlying sandstones nor from traps, but probably by ascending solutions from deep-seated sources.

Returning once more to Prof. Van Hise's paper, we find that however his theories may apply to the other deposits, they apply very largely to copper-bearing rocks. His first premise is that the greater number of ore deposits are the result of work of underground water. His second is that the material of ore deposits is derived from rocks within the zone of fracture. This would seem to be true, and there are many reasons for believing that the copper is derived from the associated igneous rocks. His third premise is that by far the major part of the depositing water is meteoric. By this he means that it is derived from the air, rain water which has worked down into the ground. In view of the composition of the water at considerable depths above given on the Keweenawan Range,

[1]Loc. cit., p. 353. See also pp. 414, 429.

it seems probable that this is not true, but that the largest part of the water may either have been buried originally with the sediments (he tells me he would class this as meteoric), or occluded in the original magma, as he suggests. It is a subject for further investigation, just how much of these three classes of water we have involved.

His fourth premise is that the flowage of the underground water is caused chiefly by gravitative stress. If this is true, I believe it may be, then it follows, as Van Hise himself has remarked (p. 417), that if the copper is most concentrated along the higher parts of the outcrop it must be formed by descending waters; moreover, as he also calls attention (p. 412) in case of the minor flexures and pitching folds in the bed, if the waters are descending the richest parts should be in the troughs of these folds, or possibly on lines leading from an anticline down to the trough of the folds. Referring once more to Plate 10, of Vol. VI., Part II, it will be seen that in such a case the copper of the Baltic and Trimountain may be expected to chute to the north when followed down. So should the mines around Calumet, while the Quincy mine should chute southwestward. The Winona mine also seems to chute southward under the swamp. And yet, as the flowage of water is under gravitative stress, it must be remembered that it will take a considerable difference in head for a fresh water to move or balance water with a specific gravity of (1.1898) a fifth more. We have already referred to the possible effect of faulting in promoting circulation. Moreover, the Keweenawan series consists mainly of a great series of lava flows, many of them over 100 feet thick. (See as an illustration of this, the section of Tamarack shaft No. 5, and correlated beds next following.) They are not likely to have lost heat for a long time after their effusion, in fact very likely not before their burial under succeeding flows,[1] so that for thousands of years the remnant heat of the effusions and the heat of the later intrusions may have aided the circulation, and particularly the solvent action of the water, as Van Hise (pp. 300, 346, 774), but more particularly J. F. Kemp and others have insisted. And yet the accumulation of copper in the Nonesuch belt of sandy shales, made up of lava sand, would indicate that it is the chemical character of the lavas rather than their heat which is most of importance. The source of the copper, Pumpelly considers to be sulphides originally deposited and leached out and reduced by the ferrous iron. This may be so, and

[1] In the succession of flows noted in the Isle Royale drill cores of Vol. VI and the Tamarack shaft, and other sections studied if there had been a long interval between flows and they had been exposed to air, the amygdaloids would have decayed to red clays and iron ores, and if they had been long enough under water there would have been more or less deposition. As is obvious from the Tamarack section, there is but very little deposition, and while there may have been some contemporary decomposition, of the amygdaloids—in fact probably has been, and it may have helped in the copper concentration, yet in very many cases, it is clear that it did not progress far before the next flow came. In fact in some cases an effect on the marginal grain of the underlying flow is indicated. Now, just for illustration's sake, if (p. 245 of the Isle Royale report, Fouqué and Lévy's observations) an ophite cooling in about six days has augite grains 0.03 square millimeters in area, then one which has them about 50 square mm. in area, like the Greenstone 120 feet from the wall, would take about (6 × 50 ÷ .03) 10,000 days before it had actually consolidated, that is, it would be between twenty and thirty years before the center of a sheet 240 feet thick had fully consolidated, and it would still be red hot. But the increase of the grain of the augite clean to the center shows that it must have been during a very early stage of cooling, and a glance at figures 1 and 2 on pages 205 and 206, shows that after more than ten times that lapse of time, say 200 to 300 years, the temperature at the center would still retain something like an eighth of its original excess of temperature over the country rock. The temperature toward the margin decreases of course, and the total amount of calories yet left in the flow will be readily found by integrating equation (11) or (12) of the Isle Royale report. Of course these figures make no pretense to accuracy. We have no right to apply Fouqué and Lévy's observtions on the grain of a rock of one composition off hand to another. Yet the order of figures is likely to be the same, and it is plain that if the Tamarack cross section has some fifty flows, and this section only represents a third or less of the whole pile of flows thus rapidly piled on each other there may have been temperatures near boiling tens of thousands of years after the formation of the pile, during all of which time the zeolites we now see may have been forming. Obviously, too, there will be a large amount of energy to promote aqueous circulation.

yet it is strange that we see so little of sulphides in the original rock or of sulphates in the secondary minerals. I have seen some fine selenite from the National mine, but in general sulphates are rare. The arsenides and sulphides that do occur are very peculiar, occurring mainly in the veins, and perhaps rather more frequently, as at Mount Bohemia, associated with the acid rocks. There are signs that at least at times they are secondary after the native copper. It has occurred to me that possibly a ferrous or ferric chloride containing a trace of copper was an early volcanic emanation. It is, however, also true that olivine, which is one of the earliest minerals to develop, contains ferrous silicate with which is likely to be associated a trace of copper and nickel. Furthermore, under the microscope the olivine, an early formed mineral, appears to gather at the sides of this dike and the top of the flow. Analyses (Vol. VI. and here) seem to indicate the same thing in the variation of the magnesia and iron.

Thus the copper may have been concentrated, first, with the olivine in amygdaloid tops or residual chlorides; secondly, by leaching out of the olivine, which decomposed either by atmospheric action and meteoric waters, or immediately after the outflow of the lava in presence of the waters (mineralized and perhaps hot), buried with this formation; thirdly, by reactions due to the circulation downward of this water set up by the uplifting of the edge of the great Lake Superior synclinal and attendant faulting. It must also be remembered that according to the earlier geologists there has been enormous erosion, which, according to L. L. Hubbard's theory (VI., p. 94), may be in part replaced by a sliding of the upper beds on the lower for miles. In either case there may have been a considerable migration downward, in the porous belts of the formation, of the material of the strata and the original water thereof.

There is yet much to be learned, but three things appear to me to be extremely probable: the copper was associated with the original lava flows; that originally deposited water or gas has been an important factor, possibly merely in bringing the copper into solution, and that the water circulation which finally precipitated the copper was downward.

It is chemically reasonable and accords with the analyses from the Quincy, Calumet, and Tamarack[1] mines to suppose that the copper is in solution in the strong solutions of earthy chlorides.

That it should be precipitated by solutions of alkaline carbonates is quite natural, and entirely in accord with its occurrence in association with calcite, and also in accord with the fact that silica has evidently been dissolved by the same waters. Electrochemical action undoubtedly attended the deposition of the copper. Whether it would commonly be called the cause, or more ordinary chemical reactions such as those indicated were the cause, remains to be seen. Faulting might cause alkaline carbonate solutions to be brought against earthy chloride solutions.

It is apparent, however, that we need still to test the rival theories. We need to trace some one horizon, some one conglomerate or flow continuously through and survey it carefully and accurately to determine the minor flexures. Dr. L. L. Hubbard has done this in part, but the work is not complete.

[1]Pages 143 to 166, 243.

THE TAMARACK MINE CROSS-SECTION

AND THE

KEWEENAWAN LODES.

THE KEWEENAWAN
ABOVE THE CALUMET AND HECLA CONGLOMERATE,

ESPECIALLY BASED ON THE RECORDS OF THE CAPTAINS OF THE TAMARACK MINE SHAFTS AND SAMPLES AND RECORDS PRESERVED BY THE ENGINEERS, R. M. EDWARDS AND W. E. PARNALL, JR.

It will be noticed that I have made some changes in the belts, from those given in previous publications and reports, in some cases throwing together several belts, only one being the true amygdaloid, the others either zones or alterations or slips. As to the practical importance of this, it may be noted that a thick flow is liable to be more persistent and farther traceable than a thin, and that its grain, lustre mottling, etc., is liable to be coarser at the center, and so it is important to recognize these big belts. The lustre mottling is due to the augite crystalline patches. In the normal ophite they are 1 mm. across within ten feet of the bottom of the flow, and then increase toward the center a millimeter for every 15 feet or so. Moreover the belts of faulting and alteration are probably of importance in the stratigraphy of the range and the concentration of copper.

The samples preserved by the mining captains are generally taken from the top of each belt as they observed them, and therefore do not show the true coarseness of the intermediate belt of trap. One object of presenting this section at this time is to show the importance of the grain, and how different mining men may differ in interpretation of records, which are not fundamentally so very different, and how easy it is to confuse the typical amygdaloid with porphyritic melaphyre or trap, and altered melaphyre or sand amygdaloid. If specimens were taken of the coarsest mottling in every belt of trap it would be possible to detect faults, and to know more certainly the size of the flows, than when samples of the trap belts are taken close underneath the amygdaloid, as is usually the case, if kept at all.

The examination of the specimens has often been only with the eye or hand lens, but quite a number of sections have been made. Relative to the systematic classification, I would refer to the Isle Royale report, in which the same series of rocks are treated. Referring to the more recent works of Cross, Iddings, Pirrson, and Washington, it is apparent that the series of Keweenawan flows are mainly dosalic, yet nearly salfemic, and perfelic, that in sub rang they are presodic, but in rang, they may run in the same flow from alkalicalcic at top to docalcic at bottom, e. g., from andose to hessose; generally they are hessose, but practically on the line between hessose and auvergnose. The same variation is noted in comparing different flows and is constantly associated with differences of texture so that I have called the former porphyritic melaphyre or porphyrite (compare augite andesite, andose and camptonose) and the latter ophite melaphyre or ophite, compare tholeyite and hessose and auvergnose.

Pumpelly's terms, ashbed diabase and lustre mottled melaphyre are nearly equivalent.

One term I use that they do not, that needs explanation. A glomeroporphyrite is a rock in which the crystallization at the time the feldspar phenocrysts were formed, went so far that these latter are more or less aggregated and bunched together. It is mainly found in the alkalicalcic flows, I think.

Tamarack shaft No. 5, went through 41 feet of peat and 5 feet of gravelly hardpan (till), before striking bed rock, began Aug. 7, 1895,—Jan. 1, 1896, 140 feet.

On the lower side of the shaft they average 11 feet lower than the figures given. See note book 99, p. 88, Portage Lake Mining Gazette, March 24, 1901, also Lake Superior Mining Institute, Vol. VII, p. 50.

1. Amygdaloid (T5b1, on N. W. side); amygdaloidal trap (T5b2); and amygdaloid (T5b3, 20 to 27) at center of shaft. Total thickness, 8+6+13 =27+ (21.2).[1]

Compare belt 22 at the Copper Falls drift, and the Isle Royale drill hole IX, 482-493.

2. Conglomerate (T5b4, 27 to 57 at center, 46 at eastern end). Thickness, 30; total 45.3 feet (23.8).

I. R. XI. 493-499 and belt 23 at the Copper Falls adit.

3. Amygdaloid (T5b5, 46-139, on the upper, 68-161 on the lower side) and trap (T5b6, 139-185).

Thickness, 139 (110) feet; total (155.2) feet.

Light colored zeolitic amygdaloid, and a dark chloritic porphyrite sp. 17674-5.

4. Conglomerate (T5b7, 185 to 195 feet). Thickness 10 (7.9) feet; total (163.1) feet.

Mainly feldspathic pebbles, but some basic. Rieder says it is a scoriaceous conglomerate of the ashbed type, and may include the amygdaloid top to the sheet below, which is of the feldspathic "ashbed diabase" type that has a rough, broken "aa" surface, which is characteristic of the "ashbeds." Sp. 17656. Probably Marvine's conglomerate No. 35 of his Eagle River section, Nos. 25 and 26 of the Copper Falls adit, and the Island mine conglomerate. I. R. X. 170-193.

5. Trap (T5b8, 195 to 340 feet).

Thickness, 145 (115) feet.

Fine grained porphyrite of the Tobin porphyrite type, feldspar abundant, though the porphyritic texture is not conspicuous. "Ashbed diabase." Sp. 17657.

Compare on Isle Royale, X. 193-306=113 (110) feet thick, and of the same petrographic character.

U. M. the augite is in idiomorphic granules. The feldspar extinctions indicate Ab_1 An_1.

The olivine has been largely changed to iron oxide.

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[1]Distances actually measured, usually vertical, are given without parentheses, actual thickness and distances reduced to distance perpendicular to the beds by multiplying by cos 37½° = .795 are given in parentheses as in Vol. VI. Reference as to a given belt in different shafts are indicated by b. Thus T 5b1 means belt No. 1 in the mining section of Tamarack No. 5. TJ1b 20 means the twentieth belt recorded in No. 1 shaft of the Tamarack Junior Mine, now an Osceola property.

6. Amygdaloid (T5b9, 340-395) and trap (T5b10, 395-627).
Thickness, 55 (43)+232 (183.1)—(227).
Total (505) feet.

Porphyritic melaphyre verging toward ophite. This probably includes more than one sheet of porphyrite, but it may be one thick flow which is at the bottom more augitic,—a feldspathic ophite. Sp. 17658, 17659, from T5b9 and Sp. 17660 (ophite), 17661, 17662 from T5b10. This is equivalent to T4b1, T4b2, 347 and T3b1 to T3b3, 122. Sp. 16401 (ophitic).

Compare also I. R. X., 335-415 analyzed and studied for grain variation. The magma of this flow seems to have been of such a character that a more and less augitic portion readily separated.

U. M. 17658, shows iddingsite very abundant, the amygdules are of chlorite and calcite.

U. M. 16402, shows labradorite in large patches of augite; olivine just altered and with a strong pleochroism between yellow and green, remarkably abundant and embedded in augite.

7. Amygdaloid (T5b11, 627-667).
Thickness, 40 (31.7).
Total (537) feet.

Sp. 17663 to 17667. These specimens show signs of fault slips, clasolitic seams of sediment, crushed amygdaloid, etc.

These indicate that there has been much motion in this belt which may be thus in part cut out. It might even represent the fragments of several flows. It is beter shown in T3 and T4,—T3, 122-178, Sp. 16403, 16404 and T4, 347-409, 44.5 to 49.3 feet. It is probable, therefore, that 16 feet or more are here cut out by a fault.

U. M. 16403, is an ophitic melaphyre, but with amygdules, and much smaller feldspar than 16402.

8. Conglomerate (T5b12, 667-692)..
Thickness 25 (19.8).
Total (557) feet.

Sp. 17668 to 17670. This is equivalent to T3b4, 178-181, and T4b5, 409-413, 16504. Possibly the slide above here has in T3 and T4 cut out of the conglomerate and amygdaloid below instead of the overlying trap.

This is the "Hancock West" conglomerate, Marvines No. 17, the Ashbed slide, I. R. X., 413 to 426, No. 44 of the Eagle River section. This horizon is characterized by a large bed above, in which, near the bottom, the augitic magma has so accumulated as to give some lustre mottling and make it an ophite (See Vol. VI., part 1, p. 64.), while beneath is a hard feldspathic sheet with a clean conchoidal fracture.

9. Trap (T5b13, 692-711).
Thickness—19 (15).
Total (572) feet.

Amygdaloid not noted in T3 or T4 in which beds 13 and 14 may have been wanting, or planed off by slide?

Compact porphyritic melaphyre with small green feldspar phenocrysts.

Equivalent to T4b6, 413 to 476, Sp. 16405, and T3b5, 191 to 243, with a thickness of 63 (50) or 52 (41) feet.

10. Amygdaloid (T5b14, 711 to 734), Sp. 17672, and trap, T5b15, 734 to 784, Sp. 17673, 17674.

Thickness, 73 (57).

A porphyritic melaphyre of the type I have called Tobin porphyrite. The amygdaloid has some fine red sediment mixed in, and is of the ash-bed type, and in it there was some water encountered. The trap is a tough grey trap, not as dark as the more augitic varieties, which made sinking very slow. The drill cores in this type on Isle Royale were long. This should be good road metal.

U. M. 17673, augite granules idiomorphic, olivine scanty, feldspar symmetrical extinctions often 4°.

11. Amygdaloid (T5b16, 784 to 808), and trap (T5b17, 808 to 920), Sp. 17675.

Thickness, 136 (108) feet.

Total, 737 feet.

Another Tobin porphyrite, with an amygdaloid like the flow above and a similar hard, fine-grained porphyritic trap which made slow sinking, and bears the strongest resemblance to the beds at bottom of drill hole 1X and the top of VIII, on Isle Royale.

12. Amygdaloid (T5b18, 920-927), Sp. 17676, and trap, (T5b19, 927 to 1041), Sp. 17677, 17678.

Thickness, 121 (96) feet.

Total, 833 feet.

Porphyrite.

Amygdaloid like the ones above, somewhat more laumonitic in T5, and a thin green porcelain like decomposition seam was noticed in the trap (datolite?).

The trap is a coarse, feldspathic glomeroporphyrite, the feldspar phenocrysts being gathered together in bunches that show that the crystallization had advanced pretty well before the last motion.

This is the lowest of this series of feldspathic melaphyres, its base being 276 feet below the Hancock West conglomerate.

In T4 we find that T4b9, 627 to 642, Sp. 16409, A. B., is classed as a thick belt of amygdaloid, 93 feet thick, and next underneath comes a well marked dark lustre mottled ophite, with olivine, Sp. 16410, and the bottom of this belt is given as 262 feet below the Hancock West conglomerate.

It is pretty clear that the bunches of feldspar phenocrysts have caused this whole flow to be classed as amygdaloid in T4 and T3.

T3b8, 389-499, Sp. 16474, also corresponds in part, but more or less of the bottom of T3b8 and T4b9 may be the amygdaloid of the underlying flow.

U. M. 16409A, is a much decomposed glomeroporphyrite, while B shows low angled feldspar, scanty idiomorphic augite, conspicuous olivine. 16410 shows scanty augite, abundant altered olivine, labradorite Ab_2 An_3, but with zonar varying extinction.

[13. 14. 15. 16.

Amygdaloid (T5b20, 1041 to 1194 feet), Sp. 17679, 17680, 17681 (122) feet, is undoubtedly a composite belt really containing one or more flows, as the records of the shafts T3 and T4 show. Together with the trap, T5b21, 1194-1212 (14)—which is a dark, typical ophite, and another

composite belt, T5b22, 1212-1368, Sp. 17683 to 17684, (124) total, (260) feet, which is described as "amygdaloid with bunches of trap in it, and has at the bottom blue clayey flucan," we have the imperfectly described and separated representatives of at least four distinct beds of ophite, recognized in T4 and T3, probably decomposed in T5.]

13. Trap T3b9, 499-539, with possibly part of T3b8), 40 (32), and T4b10, 742-770 (with possibly a part of T4b9) Sp. 16410, 28 (22).
This is a fresh black ophite, with two feet of hard, fine-grained, typical olivinitic trap at the base, above T4b11.

14. Amygdaloid (T3b10, 539-610, and T3b11, 610-651), (89) and T4b11, 770-823, and T4b12, 823-865, Sp. 16411 A-C, (76).
U. M. 16411B, augite mainly gone, quartz, secondary, olivine pseudomorphs conspicuous.
16411C, ophitic melaphyre, but the augite is scanty, the olivine conspicuous, the feldspar in two generations, one old, corroded, the other an andesite.

15. Amygdaloid (T3b12, 651-772, and T3b13, 772-792), (112), and T4b13, 865-963, and T4b14, 693-988, Sp. 16413-4 (98).
A well marked ophite, somewhat disturbed, slickensided and altered.
U. M. the feldspar is labradorite, Ab_2 An_3.

16. Amygdaloid (T3b14, 792-881), (71) and T4b15, 988-1086, Sp. 16415 A-B (78).
One or more small flows, disturbed and charged with laumonite.
U. M. the feldspar is labradorite, Ab_2 An_3.

17. Conglomerate (T5b23, 1368 to 1391).
Thickness, 23 (17).
Total, (1110) feet.
This conglomerate was sandy on top, 17685, and then conglomerate 17686. It is the Pewabic West, Marvine's conglomerate No. 16, T3b15, 881-916, T4b16, 1086-1110, Sp. 16416 B-C.
It has the same sandy streak on top also in T4, Sp. 16416.
It is generally red and has some felsitic pebbles, but others more basic, and an abundant calcareous cement.
T5 is 282 feet deeper than T4 and 487 feet deeper than T3.
U. M. fragments are (1) porphyry with micropegmatite ground mass; (2) epidote; (3) albite; (4) spherulitic porphyry (microfelsite), calcitic cement.

18. Amygdaloid (T3b24, 1391-1408), and trap, (T5b25, 1408-1425).
Thickness, 34 (27).
Total, (1137) feet.
T3b16, 916-926, and part of T3b17, 926-984, Sp. 16477, 16478 (53).
T4b17, 1110-1122, T4b18, 1122-1150, Sp. 16417, 16418 (32).
With agates and delessitic amygdules, a fine-grained labradorite porphyrite.
U. M. 16417 shows chloritic amygdules, a marginal form of melaphyre, no olivine.
16418, shows idiomorphic augite prisms.

19. Amygdaloid (T5b26, 1425-1435) and trap, T5b27, 1435-1452.
Thickness, 27 (21.5).
Total, (1159) feet.
No samples seen.

20. Amygdaloid (T5b28, 1452-1462), and trap, (T5b29, 1462-1834), Sp. 16483½, 16485, 16486.
Thickness, 382 (304).
Total, (1463) feet.
"Mixed bed of amygdaloid and trap," a big flow of melaphyre porphyrite, often very feldspathic and glomeroporphyritic, which I think is the one just above the Pewabic and Quincy lode. In T5 it showed some sheet copper on the seams.
The middle specimen is very coarse and feldspathic. There may be more than one flow but the records as kept by the various mining captains do not sharply distinguish the feldspathic and amygdaloidal belts.
T3b18, 984-1014, Sp. 16479, and
T3b19, 1014-1204, Sp. 16480, correspond to this flow and probably also
T3b20, 1224-1267, Sp. 16481, which is only a belt with bunches of feldspar, not amygdaloid.
T3b21, 1267-1315, Sp. 16482, will then also be included.
Salt water was struck in this belt in No. 3, and there may be a slip here.
T3b22, 1315-1342, is probably a belt like T3b20, so that T3b23, 1342-1372, will be the last trap belt of this flow, which makes the thickness as in T5 and T4.
Thickness, 388 (307) feet.
Compare specimens 16483, 16485, 16486.
In the same way in No. 4, we have
T4b19, 1150-1194. Amygdaloid, reddish, with laumonite, Sp. 16420,—a considerable part of this belt probably belongs in the flow above.
T4b20, 1194-1200. Trap, Sp. 16421.
U. M. glomeroporphyritic, with Ab_5 An_3.
T4b21, 1200-1347, apparently a coarse, very feldspathic center of the same belt. The feldspar is often reddish, and big green flecks may be pseudomorphs of olivine.
Probably we should include—
T4b22, 1347-1543 (or 1453). Recorded as amygdaloid, but from the samples, Sp. 16422, much the same as the previous belt, with few amygdules and much red feldspar, U. M. a glomeroporphyrite, with iron oxide growth forms.
Then also we must include
T4b23, 1543-1567, a trap, dark chloritic, greenish but feldspathic, like some belts south of Lake Richey on Isle Royale. U. M. Sp. 16423, is a glomeroporphyrite.
T4b24, 1567-1582, while classed as "amygdaloid" is really a porphyrite with large feldspar phenocrysts, Sp. 16424. Augite is scanty.
T4b25, 1582-1595, classed as a "trap," is really a porphyrite with feldspar phenocrysts up to 1 cm. long. Sp. 16425, slightly ophitic with an andesite feldspar.
Through all these belts no genuine amygdaloid or flow margin can be recognized in the samples saved.

Total, 445 (less 44—for part of the belt T4b19, improperly included (353—35) feet.

The difference in the earlier reports of the mining captains on amygdaloid flows in shafts so near together, shows that they are probably not genuine amygdaloids, but perhaps more altered, more porphyritic or more feldspathic streaks in the one great flow.

21. Amygdaloid (T5b30, 1834-1857), Sp. 16487.
Trap, T5b31, 1857-1916, Sp. 16488.
"Amygdaloid," T5b32, 1916-1924, Sp. 16489.
Trap, T5b33, 1924-2011, Sp. 16490A and 16490.
Total, 183 (140).....(1603) feet.
Pewabic and Quincy lode?

The amygdaloid at the top is well marked, the bubble cavities being filled with chlorite and calcite, Sp. 16487, and epidote and other crystals, 16426, so that the correlation of T5, 1834=T3, 1372=T4, 1595 is a reliable one within the limits of the amygdaloid belt. The trap becomes pretty close grained with light green feldspar, and green jaspery or datolite seams. T. 5b32 is very feldspathic and decomposed, with reddish feldspar, yellow-green epidote and some dark green chlorite spots. It is one of Pumpelly's pseudamygdaloids, not a real amygdaloid. Sp. 16490, T5b33 is a regular glomeroporphyrite with occasional large feldspar phenocrysts.

T5 reached 2015 feet Jan. 1, 1898.
This corresponds to
Amygdaloid, T3b24, 1372-1435 feet. Sp. 16487.
Trap, T3b25, 1435-1583
211 (168)

Evidently in this shaft the decomposed belt, T5b32=T4b28, was not present, or was not counted as amygdaloid.

It may or may not be one, though Sp. 16427 suggests to me that it is the ophite base of a feldspathic melaphyre.

And this also corresponds to

Amygdaloid. T4b26. 1595-1611. Sp. 16426 (U. M. much altered, yellow epidote).
Trap T4b27, 1611-1652. Sp. 16427 (U. M. much altered, andesitic).
Amygdaloid, T4b28, 1652-1730. Sp. 16428 (U. M. much altered, marginal),

though classed as an amygdaloid, appears to be largely a badly decomposed belt with vein matter, and a little copper and clasolitic sediment.
T4b29, 1730-1806. Sp. 16429.

Total, 211 (168)

T4b27 is a feldspathic ophite like T4b23, and some of the Phelps Island rock of Isle Royale and T4b29, is more coarse with a marked diabasic texture, much plagioclase, and occasional large feldspar phenocrysts, a porphyritic melaphyre.

T4b28 may include an amygdaloid which has acted as a line of weakness and been faulted out or overlooked in T3.

The decomposed and copper-bearing belt, T4b28, 1652-1730, covers the corresponding horizon of T5b32, 1916-1924.

U. M. Sp. 16429, is a doleritic ophite, with low angled feldspars, and chlorite interstices, the chlorite occurring as a rind; zeolite also occurs.

22. Amygdaloid, T5b34, 2011-2037. Sp. 16490½.
Trap T5b35, 2037-2130
119 (95).....Total (1698)

The Sp. 16490½, is not typical and rather coarse grained, so that if the correlations suggested are right, this might be considered part of the belt below. The specimen of trap has an interesting red aplitic seam of oligoclase, like those often connected with gabbros. It is still feldspathic.

This may correspond to
T3b26, 1583-1613, Amygdaloid,
T3b27, 1613-1635, Trap,
T3b28, 1635-1676, "Amygdaloid," appears to be really a streak of crushed matter along a fault.
T3b29, 1676-1705
122 (97)
and
T4b30, 1806-1891, Amygdaloid, Sp. 16430 (U. M. is a rather feldspathic ophite).
T4b31, 1891-1927, Trap, Sp. 16431, like Sp. 16423, feldspathic.
121 (96)

Sp. 16430, called amygdaloid, proves to be a "pseudamygdaloid," was a much decomposed specimen and very likely may represent parts of T3b26, 27 and 28, especially if the difference in depth (about 222 feet) of corresponding levels of T3 and T4 does not vary much.

Compare TJ2, 417.25—440.75, a belt which carried some copper, with T3b28.

23. Amygdaloid, T5b36, 2130-2169.

24. and trap T5b37, 2169-2278.
Total thickness, 148 (118).....(1738)

The top is a well marked amygdaloid with thomsonite, and apparently from Sp. 16432, there was a belt of amygdaloid overlooked in the trap. It still belongs in the porphyrite melaphyre type, Pumpelly's ordinary diabase.

This corresponds probably to
T3b30, 1705-1728, "Amygdaloid."
T3b31, 1728-1740, trap.
T3b32, 1740-1785, "Amygdaloid," probably in part at least.
T3b33, 1785-1820.
Thickness 115 (92).
Also
T4b32, 1927-1947, Amygdaloid, Sp. 16432. U. M. a genuine amygdaloid with fine-grained quartz, epidote amygdules, and two well marked generations of andesite.
T4b33, 1947-1967, trap, Sp. 16433.

Sp. 16433 is reddish brown with small lath-shaped feldspar phenocrysts. U. M. It belongs to the Minong type, has andesitic feldspar, and idio-

morphic granules and sharp prisms of augite, and some olivine. Sp. 16434, also apparently represents the very bottom of the bed. Sp. 16435 is much like 16433. Unless there is some mistake, there are two flows here.

T4b34, 1967-2003, amygdaloid, Sp. 16434, U. M. glomeroporphyritic.

T4b35, 2003-2033, trap, Sp. 16435, U. M. texture intersertal, scanty granular augite, with olivine pseudomorphs.

107 (85)

The specimens are still feldspathic and belong to the porphyrite type.

25. T5b38, 2278-2292, amygdaloid.
T5b39, 2292-2327, trap.
Thickness, 49 (38).
Total, (1777).

This corresponds to

T3b34, 1820-1863.
T3b35, 1863-1878.
58 (46)

T4b36, 2033.6-2048.3, Sp. 16436, amygdaloid with calcite filling. U. M. calcite and zeolites, trichitic feldspar, scanty augite.

T4b37, 2048.3-2117.6, Sp. 16437, trap.
84.0 (67)

Sp. 16437 is medium fine-grained and not markedly porphyritic.

U. M. it is glomeroporphyritic, with andesite, scanty augite, olivine pseudomorphs, calcite and zeolites.

26. T5b40, 2327-2349, amygdaloid.
T5b41, 2349-2374, trap.
47 (37).....Total, (1814)

Whether T5b42 is a real amygdaloid, overlooked in the other shafts, we cannot be sure. It may be merely a glomeroporphyritic belt.

This may correspond to

T3b36, 1878-1905, in part amygdaloid.
T3b37, 1905-1970, trap.
92 (72)

Compare TJ2, 673.75-695.5.

T4b38, 2117.6-2145.7, amygdaloid, Sp. 16438.
T4b39, 2145.7-2208.2, Sp. 16439.
90.6 (72)

Sp. 16439 is a coarsely mottled ophite, with olivine perhaps represented by serpentine. U. M. feldspar is andesite.

Sp. 16438 has calcite amygdules, but is of the same type as T4b22 and T4b25, a glomeroporphyrite, the whole flow being a feldspathic ophite, tending to differentiate. U. M. it shows somewhat agglomerated feldspar.

27. T5b42, 2374-2411, amygdaloid.
T5b43, 2411-2484, trap.
Thickness, 100 (79).....Total, (1893)

This has by some been correlated with the *Pewabic amygdaloid.*

T3b38, 1970-2018, amygdaloid.
T3b39, 2018-2039, trap, Sp. 16491.
Thickness, 69 (45).

T4b40, 2208.2 amygdaloid, Sp. 16440. U. M. trichitic marginal plagioclase, amygdules with yellow and green epidote and quartz.

T4b41, -2257, trap. Sp. 16441, dark, with a few large feldspar phenocrysts. U. M. verges on ophite, rather scanty augite, with oligoclase.
48.8 (39)

The amygdaloid marking the top of this belt varies so in position in the different sections, that it is hard to explain. Is it near the end of the sheet?

28. T5b44, 2484-2513.
T5b45, 2513-2569.
Thickness, 85 (67).....Total, (1960) feet.
This may correspond to
T3b40, 2039-2068, Sp. 16492.
T3b41, 2068-2111, Sp. 16493, a very dark ophite.
Thickness, 72 (57).
Compare with TJ2, 807-837.
Also with
T4b42, 2257.5-2305.7, amygdaloid, Sp. 16442.
T4b43, 2305.7-2333.7, trap, Sp. 16433.
76.2 (60)
Sp. 16643 is a very dark, massive labradorite or porphyrite=Sp. 16493.
U. M. feldspar is Ab_3 An_4, augite scanty.

29. T5b46, 2569-2630, amygdaloid, (71).
T5b47, 2630-2684, trap, (54).
Thickness, 115 (91).....Total, (2051) feet.
As the extra breadth of the amygdaloid belt indicates, there may be here two flows, or the porphyritic character of the two sheets may have led more of their contact belt to be classed as amygdaloid.
Compare:
T3b42, 2111-2143, amygdaloid, Sp. 16494.
T3b43, 2143-2164, Sp. 16495.
53 (42)
T4b44, 2333.7-2416.6=(83), amygdaloid. No samples.
Compare TJb1, 500.4, TJb2, 2887.4, T3, 2111, and T4, 2333.7.

30. T5b48, 2684-2708, amygdaloid.
T5b49, 2708-2753, trap.
69 (55)
Compare T3b44, 2164-2198, Sp. 16496.
T3b45, 2198-2247, Sp. 16497.
83 (66)
This probably represents a small part of T4b44, 2333.7-2416.1; no Sp. and the whole of T4b45, 2416.6-2471.8=(55.2+), Sp. 16445. Of Sp. 16445 there are two pieces, one amygdaloid with thomsonite, possibly T4b44, mislabeled, the other, a fine-grained, dark purple melaphyre, a diabasic melaphyre.

The porphyry tuff, jasper bed (see Isle Royale report, p. 74), at 460 feet in T1, seems not to have been noticed elsewhere.

U. M. 16444 is an ophitic melaphyre with large feldspar phenocrysts.

16445 shows low angled andesite.

Compare TJ1, TJ2, 1033, Red Jacket or Whiting shaft of Calumet and Hecla 1215, T3, 2247, T4, 2471.

31. T5b50, 2753-2796, amygdaloid.
T5b51, 2796-2981, trap.
Thickness, 228 (181) ..... Total, (2329) feet.

This is the great sheet known as the "Greenstone," which is the "backbone" of Isle Royale, (drill hole VI, 124-363. See Volume VI, part 1, pp. 74, 126, 128, 134, 244) and is also a prominent ridge, being there much thicker, probably several hundred feet, with proportionately coarser mottling of augite, just north of the Cliff, Central, Phœnix, and other mines.

It is a type of ophite melaphyre, though in many places as coarse as many a gabbro. Yet the flow as a whole, contains glassy matter.

This corresponds to
T3b46, 2247-2274. Sp. 16498 is a fine-grained ophite.
T3b47, 2274-2513. Sp. 16499.
Thickness, 266 (212).

Compare TJ2, 1033.

Also to T4b46, 2471.8-2479.4. Sp. 16446, amygdaloid, fine-grained with small amygdules, zeolitic.
T4b47, 2497.4-2747.2, Sp. 16477. Fine-grained trap with small amygdules.
Thickness, 265.4 (211).
Sp. 16447 is not at all typical.

32. T5b52, 2981-3020 (or 3000 L. S. M. Institute report).

Conglomerate. *The Allouez conglomerate, one of the most important datum planes of the series, Marvines, No. 15, the Albany and Boston* (Peninsula and Franklin Junior).
Thickness, 39 (31) .....Total, (2360) feet.

Corresponds to
T3b48, only 6 inches at 2513. Sp. 16500.
T4b48, 2747.2-2754.2. Sp. 16448. U. M. decomposed syenite pebble?
T2, at 1256.
T1, at 876.
Calumet and Hecla, Red Jacket or Whiting shaft at 1656 feet.
Isle Royale drill hole VI., 363-386 feet.
T1, at 670 feet.

33. T5b53, 3020-3061, amygdaloid.
T5b54, 3061-3114, trap.
94 (75)

Corresponds to
T3b49, 2513-2588, amygdaloid.
T3b50, 2588-2629, trap.
116 (92)

T4b49, 2754.2-2826.5, amygdaloid. Sp. 16449.
T4b50, 2826.5-2875.9, trap. Sp. 16450, an ophite. U. M. like 16414, olivine pseudomorphs.
121.7

The belt T4b49-50, also corresponds to the next belt.

34. T5b55, 3114-3158, amygdaloid.
T5b56, 3158-3181, trap.
67 (53)

Compare
T3b51, 2629-2656
T3b52, 2656-2677

52

Also
T4b49, 2754.2-2826.5, amygdaloid. Sp. 16449.
T4b50, 2826.5-2875.9, trap. Sp. 16450, an ophite.
121.7

The upper belt of amygdaloid is much too broad to be one flow and corresponds to T5b53-54, and T3b49 and 50.
T4, 2826.5, is nearly =T3, 2651=T5, 3061.

35 and 36. T5b57, 3181-3221, amygdaloid.
T5b58, 3221-3320, trap.
139 (110)

This seems to represent two flows in T3, to wit:
T3b53, 2677-2703, amygdaloid.
T3b54, 2703-2720, trap.
43
T3b55, 2720-2742.
T3b56, 2742-2819.
99=142 (113)

Compare
T4b51, 2875.9-2973.8, amygdaloid.
T4b52, 2973.8-3050.4, trap. Sp. 16452, an ophite, medium coarse.
174.5

Obviously, in the smaller flows, less than 50 feet or so thick, the line between amygdaloid and trap is largely one of individual caprice, the upper flow in T5 and T4 is counted all amygdaloid and in the Red Jacket shaft the whole interval from 1700-1954 feet.

37. T5b59, 3320-3339, amygdaloid.
T5b60, 3339-3594, trap.
274 (217)

Compare:
T3b57, 2819-2834.
T3b58, 2834-3114.
295 (234)
T4b53, 3050.4-3064.5, amygdaloid. Sp. 16453.
T4b54, 3064.5-3334, trap. Sp. 16454.
284 (225)

Sp. 16454 is an ophite, but has one large feldspar phenocryst, perhaps a

pre-effusive, or "brotocrystal." U. M. a medium, coarse-grained ophite with chloritic interstices.

Compare the ophite (202) feet thick in the Red Jacket shaft at 1754 feet depth.

This ophite is just here as large as the "Greenstone," but it has not the same topographic prominence, which is another indication that the "Greenstone" (p. 263) is thicker to the north. This is, however, thick enough to be a fairly persistent bed.

38. T5b61, 3594-3630, amygdaloid.
T5b62, 3630-3691, trap.
97 (77)
T3b59, 3114-3144, amygdaloid. Sp. 16509.
T3b60, 3144-3212.6, trap. Sp. 16510.
98.6 (78)
T4b55, 3334 -3358.4, amygdaloid. Sp. 16455.
T4b56, 3558.4-3444.9, trap. Sp. 16456.
110.9 (88)

Sp. 16455 is much decomposed, dark red with epidote and calcite.

Sp. 16456 is a fine-grained melaphyre. U. M. rather fine-grained.

Compare the belt at 1310 feet in the Calumet and Hecla cross-cut to Red Jacket shaft.

39. T5b63, 3691-3730, amygdaloid.
T5b64, 3730-3769, trap.
78 (62)
T3b61, 3212.6-3235 amygdaloid. Sp. 16511, laumonite.
T3b62, 3235 -3270.3, trap. Sp. 16512.
57.7 (46)
T4b57, 3444.9-3458.7, amygdaloid. Sp. 16457, laumonite.
T4b58, 3458.7-3500.7, trap. Sp. 16458, hard, fine-grained.
55.8

U. M. Sp, 16458 is slightly glomeroporphyritic; labradorite not high ex-angled; augite scanty, granular or patchy; olivine (iddingsite) scarce; iron oxides abundant.

Sp. 16457 seems to show melaphyre fragments with a red calcareous cement, and might cover a narrow scoriaceous conglomerate, (?) the Houghton conglomerate, of the ashbed type.

Sp. 16458 is somewhat glomeroporphyritic.

Compare the amygdaloid at 1218 feet in the long Calumet and Hecla cross-cut to the Red Jacket shaft, Plate I of Vol. V, Part I, and the feldspathic melaphyre beneath.

40. T5b65, 3769 -3783 amygdaloid.
T5b66, 3783 -3784 trap.
Thickness, 78 (67).

Compare:
T3b63, 3270.3-3312.4.
T3b64, 3312.4-3366.4, trap. Sp. 16514.
96.1
T4b59, 3500.7-3535, amygdaloid. Sp. 16459 hard. U. M. ophite with feldspar not abundant.

T4b60, 3535-3611, trap. Sp. 16460.
110.3

This is an ophite, red, blotched with enclosures.

41. Houghton conglomerate absent (Marvine's No. 14)?

42. T5b67, 3847-3861, amygdaloid.
T5b68, 3861-3885, trap.
Thickness, 38 (30).

43. T5b69, 3885-3912, amygdaloid (possibly a vein breccia).
T5b70, 3912-3971, trap.
Thickness, 86 (68).

Compare:

T3b65, 3366.4-3385, amygdaloid. Sp. 16515.
T3b66, 3385 -3500, trap. Sp. 16516.
133.8
T4b61, 3611 -3649.8, amygdaloid. Sp.16461; light green.
Sp. 16461A.
T4b62, 3649.8-3719.7, trap. Sp. 16462, ophite. (March 16, 3860 feet).
108.7

Sp. 16461A appears to be a vein of breccia. Sp. 16462 is not so markedly ophite.

The Houghton Conglomerate (Marvine's No. 14), is due here, and the blotched appearance of the overlying flow and the breccia may be signs of it.

44. T5b71, 3971-3991, amygdaloid.
T5b72, 3991-4049, trap.
78 (62)

An ophite, a well identified bed.

Compare:

T3b67, 3500-3521, amygdaloid. Sp. 16517.
T3b68, 3521-3578, trap. Sp. 16518, an ophite.
78 (62)
T4b63, 3719.7-3740.6, amygdaloid. Sp. 16463.
T4b64, 3740.6-3794.4, trap. Sp. 16464, ophite.
74.7

In the Calumet and Hecla cross-cut this appears as flow (920-800).

45. T5b73, 4049-4085.
T5b74, 4085-4137.
Thickness, 88 (70).

Compare:

T3b69, 3578-3619, amygdaloid. Sp. 16519, with *copper*.
T3b70, 3619-3769, trap. Sp. 16520, an ophite.
10 1
T4b65, 3794.4-3837.1, amygdaloid. 16465.
T4b66, 3837.1-3909.4, trap. 16466, ophite.
115.0

In the Calumet and Hecla long cross-cut, this appears as a flow (800—674=128x.62=79 feet thick) of ophite with a laumonitic amygdaloid.

46. T5b75, 4137-4183, amygdaloid.
T5b76, 4183-4232, trap.
Thickness, 95 (74).

Compare:
T3b71, 3679-3733 amygdaloid. Sp. 16521, small amygdules.
T5b72, 3733-3797.8, trap. Sp. 16522, ophite.
117.8
T4b67, 3909.4-3927.8, amygdaloid. Sp. 16467.
T4b68, 3927.8-3979 trap. Sp. 16468, ophite.
69.6

Sp. 16468 matches 16522 remarkably well.

In the Calumet and Hecla cross-cut we have a flow (674 to 660, and 660 to 557, i. e., 117) (73) feet thick of melaphyre, with a brecciated amygdaloid.

47. T5b77, 4232-4254, amygdaloid.
T5b78, 4254-4358, trap. Ophite.
Thickness, 126 (100)
T3b73, 3797.8-3818 amygdaloid. Sp. 16523.
T3b74, 3818 -3898.2, trap. Sp. 16524, ophite.
100.4

Sp. 16523 has two pieces, one a well marked contact of two flows. A is the top of the lower bed, more amygdaloid.

The ophite is massive, chloritic, hard to break.
T4b69, 3979-4005, (26) amygdaloid. Sp. 16469.
T4b70, 4005 trap. Sp. 164670, ophite.

This has a quartz epidote amygdaloid (Sp. 16469). In the Calumet and Hecla longest cross-cut it is an ophite with olivine well marked and a thickness of (539—361+18=196, which x .62=122) feet, the amygdaloid appearing dark red laumonite.

48. T5b79, 4358-4386.
T5b80, 4386-4456.
98 (78)

Compare:
T3b75, 3898.2-3920, amygdaloid. Sp. 16525.
T3b76, 3920 -3970, trap. Sp. 16526, ophite.
72
T4b71.
T4b72.

This in the Calumet and Hecla longest cross-cut is a belt with augite grains (mottled) at least 2 to 3 mm. across and a thickness of (361—220= 141x.62=87) feet.

49. T5b81, 4456-4525= 70, amygdaloid.
T5b82, 4525-4636=111, trap. A heavy ophite.
181 (144)
T3b77, 3970 -4008.7, amygdaloid. Sp. 16527.
T3b78, 4008.7-4044 trap. Sp. 16528, called amygdaloid in other records and really amygdaloid.
T4b79, 4044-4065, amygdaloid with copper. Sp. 16529.
T4b80, 4065- trap. Sp. 16530, ophite.

This is the Calumet and Hecla cross-cut, an ophite with augite grains (mottles) at least 3 to 4 mm. in diameter, indicating a flow at least 80 to 120 feet thick, the belt with the amygdaloid being 220 feet wide (x.62= 145 feet thick).

The amygdaloid is chloritic with a little copper.

50. T5b83, 4636-4662, amygdaloid.
26 (20)

Not noticed in the Calumet and Hecla longest cross-cut, probably not present.

T3b81, amygdaloid. Sp. 16531.

T3b82, trap. Sp. 16532. A fine-grained black trap, appropriate to a thin flow.

51. T5b84, 4662. Calumet and Hecla conglomerate. Marvine's No. 13. T3b83, at 4183, in T4 at 4393 feet.

The Rest of the Keweenawan Section.

From the Calumet and Hecla conglomerate down to the Kearsarge amygdaloid, which is the important belt worked by the Ahmeek, Mohawk, Wolverine, Allouez (new vertical shaft), Centennial, and Osceola which has also been recently opened up by the Calumet, there are a number of sections.

In Volume V, Part 1, will be found the sections of their long drift in the foot wall, furnished by the C. and H. Mining Co. In Volume VI, Part 2, p. 130, will be found a section of the Franklin Junior, which was furnished by Mr. Pope. The long drifts from the Tamarack vertical shafts over to the lodes also show the section down to the Kearsarge conglomerate and to within 200 feet of the Kearsarge amygdaloid. A lot of work has recently been done in developing the section below the Tamarack, which I trust to take up more fully in the future and will therefore give merely in abstract for convenience of reference here.

CENTENNIAL.

Calumet and Hecla in cross-cut, 2.33 feet.

1. Amygdaloid, 27 (17) feet and trap; Sp. 16545-16550; 187 (115).

2. Amygdaloid, 54 (33) feet; ophite; 16551-16559; 441 (271); coarsest about 174 feet above its base, where the augite mottles are some 6.5 mm. across; cut by a 2 to 3 foot slip about 266 (208) feet from its base. Comparing the various cross-cuts from the Calumet and Hecla, given in Volume V, we see that either this slip has been the cause of various interpretations of the section according to the degree of alteration produced, or really is crossing the formation obliquely, so as to give different sections at different points.

3. Amygdaloid, very much brecciated lamonitic and almost conglomeritic in texture for 44 (37) feet,—then coarse ophite, 168 (103); Sp. 16561-16565.

Total from top of Calumet and Hecla to top of Osceola, (491).

In a cross-cut in the 13th level from Tamarack No. 1, it was, according to R. M. Edwards, 750 (461) feet from the bottom of the Calumet and Hecla to the top of the Osceola, the records being amygdaloid trap 35,

trap 145, amygdaloid 50, trap 220, amygdaloid (which is probably a pseudamygdaloid along a slip in reality) 20, trap 95, amygdaloid with copper 40, trap 145, to the Osceola. It is probable that strike faults produce some of this variety in sections.

Down to the Kearsarge-North Star conglomerate No. (11) are some four belts more or (412 at the Franklin Junior)—(481) feet.

This is about 1,000 feet below the Calumet and Hecla. The next 600 feet below the top of the Kearsarge are taken up by about four belts or flows, often heavy ophites, which are cut by the long cross-cut of the Calumet and Hecla. This is pretty well down to the Kearsarge amygdaloid which is one of the most important lodes, being opened by the Calumet, the Kearsarge branch of the Osceola, Centennial, Wolverine, Mohawk, Ahmeek, Allouez, and is below the top of the Kearsarge conglomerate about (880) feet. It is not far, about 200 feet, from the bottom of Tamarack shaft No. 2.

The Kearsarge amygdaloid is the top of a peculiar bed of ophite characterized, as Dr. Hubbard has remarked, by quite frequent long porphyritic crystals of feldspar (labradorite phenocrysts), which appear to be quite early formed. At the base of this ophite which is about (180) feet thick, is a sandstone or conglomerate 40 to 60 feet thick, the Wolverine sandstone (Marvine's No. 9), so that the total from the top of the Kearsarge conglomerate to the top of the Wolverine sandstone is say (1060) feet; going south it may thin to (880) feet, and the whole thickness from the top of 11 to the top of 9 around Portage lake may be not over (875) feet.

Below the Wolverine sandstone comes a broad belt which has few notable sediments and no mines. One horizon has been denoted by Dr. Hubbard the "inclusion bed," about 461 feet below. There are some heavy ophites and coarse doleritic traps such as are associated with the Arcadian and Isle Royale horizon which is below the top of the Wolverine sandstone, say (2200) feet.

Not very far below this is an important sedimentary horizon, that of conglomerate No. 8. This is quite probably the same as the Bohemia-St. Louis conglomerate which Dr. Hubbard has traced quite extensively in Volume VI. It seems to mark the upper horizon of one set of acid felsitic flows, such as occur at a number of points and the interval between it and the No. 9, the Wolverine sandstone, is perhaps (2750) feet. It is about 5,000 feet up to the Calumet and Hecla.

Below the Bohemia conglomerate horizon comes the porphyry exposed on the Torch Lake R. R. (and shown in the map of Allouez Gap, given in Volume VI) which is probably at nearly the same horizon as the Mt. Houghton and other extrusive felsites which Dr. Hubbard has described out on the point, and the felsite found at the base of the Isle Royale (Wendigo) section. We do not find these farther south, but we do find a group of conglomerates sometimes as much as 200 to 300 feet thick, corresponding to Marvine's numbers 5, 6, 7, and 8, with perhaps others intercalated, a more careful description of which may be left until later. However, between the top of conglomerate 5 and top of 8, are about 10 belts around Portage Lake, included in a thickness of about (1000) feet.

Near Calumet the presence of irregular masses of porphyry makes it difficult to give any general figure.

Below the horizon of conglomerate (5) which probably does not appear at its ordinary level there is in the long cross-cuts of the Atlantic mine on Sec. 16, down to (No. 3), the Baltic conglomerate, (2050) feet. The

flows are mainly heavy ophites with scoriaceous amygdaloids that are liable to develop normal sediments at very short notice. The Baltic conglomerate is the one not far below the Baltic lode or shear zone in the mines of the Copper Range Consolidated. Dr. Hubbard tells me that toward the south, the distance between the two increases. But this is not the base of the formation, which is nowhere visible. Toward the end of the point there must be exposed below the Bohemia conglomerate, faulting apart, not much less than 5000 feet, or below the Baltic conglomerate (No. 3) level, say (1400) feet.

East of Houghton to Marvine's conglomerate (1), there is some 2000 feet horizontally, or about the same thickness. There is no real indication even here that we are at the base of the series or beginning of the volcanic activity. To obtain any lower beds, however, we must go elsewhere. I propose, in the coming year, to have prepared a section from the Gogebic range (where the Keweenawan is said to be more nearly conformable to the Huronian) north, and see if we can find comparable horizons, and any light upon the base of the Keweenawan. It is, of course, conceivable that the lowest beds of the Keweenawan exposed there, may be overlaps of beds far from the base of the series, but that is not my present belief. There is one comment that I think worth making. From the level of the top of Tamarack No. 5 to the Baltic conglomerate No. 3, is about 11,000 feet and there are at least 12,400 feet of beds. Now, the top of Tamarack No. 5 is by no means the top of the formation, though it is not far from the top of the main series of traps and the lake shore traps most likely do not appear here. There is perhaps 1,400 feet of mixed sandstone and trap above. Then there is the great conglomerate and the lake shore trap (probably absent), above which Irving draws the line between upper and lower Keweenawan, that are 700 to 2300 feet thick, so that there is not less than 13,000 feet of the lower Keweenawan.

Above this is an unknown amount of red sandstone and shale, certainly not less than 1000 feet, for which Irving estimates 9000 feet. Now is it likely that the base of the series could ever have been buried 22,000 or even 14,000 feet at an early date in geological time (when the rate of increase of temperature, unless we adopt Chamberlin's hypothesis, was higher than at present and then steamed) without having the augite altered to hornblende as it is around the Mt. Bohemia intrusion for a considerable breadth? It does not seem to me likely. It seems probable on this ground as well as on account of the basic pebbles found in the conglomerates that uplift and tilting took place at several times during the formation of the series. One I suspect is about the time of conglomerate 8, i. e., the Bohemia; another about the time of the great conglomerate, and at the time of the basic (Nonesuch) black shales there must have been extensive erosion of the Keweenawan traps.

What the condition of the traps in the undisturbed center of the basin may be we can but guess. I suspect they will be much like many of the amphibolites (so-called diorites) of the copper country.

DEEP BORINGS

FOR

OIL AND GAS.

The position of the geologist relative to borings for oil and gas in Lower Michigan is trying. He cannot absolutely discountenance explorations with such confidence as he can predict the failures of coal explorations outside of the coal basin at Norwood or Petoskey, for instance. Neither can he promise favorable results with such confidence as he can promise brominiferous brines, or gypsum or salt. He can only say that the chances are generally unfavorable, but more favorable in some places than in others. Not a little of my time has been spent in examining borings and discussing prospects, and I thought of making quite a full report on recent borings something like that in the 1901 report. But a number of important records are not yet finished and I do not like to break up an elaborate record between two reports. The borings along the Detroit river should very soon receive exhaustive treatment in the Wayne county report and may therefore be omitted here. In this region the results so far are discouraging, as I have already mentioned, with this exception, that the quarries at Sibleys and at Anderdon, across Detroit river in Canada, dip to the southwest instead of the northwest or north, which should be the normal direction of dip. This may indicate that they lie on the northeast side of a synclinal or monoclinal to a fault, and that just northeast of them in turn is the axis of an anticlinal running and pitching to the northwest. The depth of the Sylvania sandstone in the various wells along the Detroit river indicates the same thing, the depth being less beneath Wyandotte than either above or below. This, then, would be the most favorable point to test, but the upward bend does not appear to be more than 30 feet or so, and the well of the Eureka Iron and Steel Co. (Van Alstyne) or that of the Fords (Michigan Alkali Co.) have not shown any noteworthy amounts of oil or gas. The line thus indicated produced northwest would, however, pass close to a field in Livingston county where some oil and gas has been found. Here also are oil horizons known as the Berea.

In previous reports (Volume V, and annual for 1901 and 1902) I have ventured to indicate other regions also as more likely to have the necessary structure, to wit: Khagashewing Point on Little Traverse Bay; somewhere near Manistee; an anticlinal through the city of Saginaw, probably running a little west of north; one at Port Huron; an area north of Mt. Clemens, and finally coming up from Indiana a region east of Niles.

In regard to the Manistee district, Mr. T. Percy is going to do some testing upon which, with his knowledge of this region and oil wells elsewhere, we may depend so far as he goes. A disadvantage is that the drift is thick, and the oil horizons deep. At Rapid River on the other side of Lake Michigan, the newspapers report oil to have been struck in quantity,[1]

[1]The following is given us as a test of the oil:

Milwaukee, Nov. 4, 1903.

The Cream City Development Co., City:
Gentlemen:—In accordance with your request I have carefully examined your sample of raw

(estimates ranging from 30 to 300 barrels a day) at 1,000 feet. But as I understand that the casing was not in order, and that 1,000 feet would be down in the preCambrian, and certainly could not be above the Potsdam, such estimates should be taken with great reserve. The oil may come by a leak from superficial strata.

In Muskegon, the Central Paper Co. put down a deep well and kept a careful set of samples, the results of which are as follows:—

Muskegon well No. 6. Central Paper Co., on lot 1, N. E. ¼, Sec. 34, T. 10 N., R. 17 W., about 4¼ miles from Ryerson well.

Pleistocene.		
Sand	50	50
Red calcareous clay, a little lighter than in No. 5, 126-200.		
Smooth, red, calcareous clay	183	233
MISSISSIPPIAN (SUB-CARBONIFEROUS).		
Marshall.		
Sandstone, greenish, calcareous, very fine at the bottom, a typical Marshall grit	77	310
Lower Marshall?		
Shale, dark, bluish, more or less calcareous	315	625
Limestone, a clayey and dolomitic water-lime, with selenite, like limestones of the Michigan series	35	660
Shales, blue, calcareous	185	845
Limestone, red and white, fossiliferous	25	870

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petroleum from Delta county, Upper Peninsula, Mich., handed to me for physical and chemical investigation. In the following please find the results at which I have arrived.

1. *The color of the same* is a brownish black, *the consistency is liquid though moderately viscous.*

2. *Specific gravity of your oil compared with that of other prominent fields:*

Your Delta county oil, Michigan, 0.873; Pennsylvania Petroleum, 0.801 to 0.817; Ohio Lima field, 0.816 to 0.860; West Virginia, 0.841 to 0.873; Russia Bakerfield, 0.859 to 0.871; Beaumont, Texas, 0.904 to 0 926; California, 0.920 to 0.983.

3. *The flashing point of your raw petroleum:*

You will undoubtedly understand that petroleum coming from the well must be safe for transportation, handling and for storage. Very few petroleums as they come from the well have these qualifications. All contain a greater or less percentage of naphtha, or some lighter hydrocarbons which have a tendency to reduce the flash point and make the oil easily inflammable. *The flashing point of the sample of your raw oil proves to be between 165 and 170 degrees F. which indicates that the same is perfectly safe for any kind of transportation as well as for the required storage.*

4. *Results of its fractional distillation:*

Temperature.	Percentage of distillate.
Below 150° C. or 302° F.	6.8
150-250° C. or 302-482° F.	64.3
250-325° C. or 482-617° F.	11.2
	8.6 Paraffin and vaseline, and
	9.10 Residue, which later proved to be mainly asphalt.

The first part (the 6.8%) of the above distillates contained but a very small quantity of light resp. volatile hydrocarbons (gasoline, benzine, etc.) while more than 60% of the raw oil proved to be first-class illuminants.

From the foregoing it is clear that the oil is of excellent quality, partly of a paraffin but mainly of an asphaltic base.

Very respectfully,
FR. RUSCHHAUPT.
Geologist, Mining Engineer and Chemist.

Coldwater.		
Flags, i. e., blue and green siliceous shales, with bands of very fine-grained grits, or sandstone, at times more or less calcareous	530	1400
DEVONIAN.		
Horizon of Berea.		
Shales, red and green	80	1480
Antrim.		
Shale, black, bituminous, pyritic, especially at the base	135	1615
Traverse.		
Shale, blue, calcareous	35	1650

I wrote the Central Paper Co. the letter below, and I understand that further tests may be made. I sent also sample bottles for samples of the Black Creek or Fruitport well, but mischevious boys carried them off before I got them, and the drillers did not keep a record.

Lansing, Mich., May 1, 1903.

Central Paper Co.,
Muskegon, Mich.

Gentlemen.—I send herewith blue print diagram of your well.

I presume the well is at about the same height above the lake as the Ryerson well and about 10 feet lower than the old Mason well. The bottom of your well extends down into the Traverse (Hamilton) series of blue shales and limestones. A small area of this is found near Milwaukee. Thus, the easterly dip from across the lake is some 20 odd feet per mile (1615 feet ÷ 84 miles). From your well to the Mason well the dip continues about the same as that from Milwaukee (1700—11?—1615÷4).[1]

The bed of red fossiliferous limestone which shows in your well at 845 to 870 feet is ignored in the old Mason record, but shows well in the samples from the well recently put down near the old Mason well, but on lower ground, at a depth of 890 to 904 feet. The dip is still easterly but not so great.—only about 11 feet to the mile. This is quite what we should expect for we know that this series of beds thickens going east and thins out near Milwaukee, and this is just about the dip which would be expected. Now, although the Ryerson well is not absolutely in the line of the Central Paper Co. and Mason wells, it is so nearly so that we should expect the beds in it to be deeper than in the Mason wells. This is not true. This bed and other corresponding strata appear higher in the Ryerson well, than in the new well near the Mason well,—No. V of my annual report for 1901.

Accordingly, if I wanted to try further for oil, I should go up the lake, —say on sections 15 and 16, and see if there might not be an anticlinal in that direction. The oil sand is, however, so fine-grained that it is not likely to be a free yielder unless it is struck in some exceptionally coarse

[1] The difference in depth to the same horizon minus the difference in elevation divided by the distance between the wells.

spot. It is barely possible that oil or gas might be found at the point indicated as the Dundee,—2100 feet or so down, but this would probably be of the Canada quality.

I should like to know the record of the well and the sample of the Fruitport well put down not long ago, and with your permission, I should like to send a copy of this letter to Mr. Kimball of Chicago. If we recognize that same limestone in the Fruitport well, it will be of considerable advantage.

Very respectfully yours,
ALFRED C. LANE.

In connection with the abnormal elevation of the Ryerson-Hill well above referred to, it is worth noting that as I have myself observed, it continually exudes some oil. The amount, according to newspaper[1] report, probably exaggerated, is half a barrel a day.

DIVINING RODS.

There has been considerable activity in exploration near the Indiana line, not all of it on business principles. Wells have been located on the witch hazel divining rod plan worked up to an instrument supposed to be scientific, but which is beyond my science. Many would up and down denounce it as a fake and those who work it as fakirs.

I am inclined to think, however, in some cases the person using and having bought the instrument may be honestly deluded, and I think, therefore, that it may be worth while to give a description of the instrument and its working (the witch hazel and other water diviners are similar), to show how one may fool one's self as well as others. It belongs to a class of instruments like the planchette, which are very sensitive to conscious or unconscious muscular action.[2] The Assyria well was located by it.

Two flexible rods of whalebone about a foot long corresponding to the branches of the witch hazel, issue from a weighted disk corresponding to the fork or crotch of the witch hazel divining rod, to the other side of which is secured a tube (A) containing oil, or some substance which is

Fig. 8. Illustrates divining rod instrument.

supposed to be attracted by the substance in the ground. In working it the rods are bent until their ends are parallel, as shown in the diagram at C, and are held one in each hand, the palms turned upward, and the weight also being upward. In such a position it is clear that it is in a very unstable position, and that the weight (B) has a strong leverage against the grip of the hands which have only the thickness of the rods to

[1]Grand Rapids Herald, 11/1 1904.
[2]James' Psychology. My predecessor, Dr. M. E. Wadsworth, published in the American Geologist, January, 1898, an explanation of the mechanical action of the divining rod, which however, differs radically, in that the ends of the twig fork are supposed to "enter the closed fist on the exterior side of each fist," and the difference between wrist and finger action is not emphasized.

work on. Under such circumstances, by gripping it tight, one can keep the bob erect, but the least relaxation of grip, *and what I think is more important,* a turn of the wrist so slight that I could not in watching my own wrists detect it, will let the bob over. *In fact, the wrist has vastly greater and easier control than the fingers.* Now it is easy to see from well recognized principles of modern psychology, that one thus holding it will from time to time either at points where he is otherwise led to expect oil, or from mere weariness, see it dip, quite unconscious of any co-operation on his part, if his attention is riveted on the grip of his fingers or on visions of oil, and may be led to believe the instrument full of magnetic power. So long as water is concerned and no special depth guaranteed, it is easy to see that here in Michigan, in almost all cases it will succeed. Possibly a little of that "horse-sense" by which animals are supposed to divine the presence of water may linger in some men yet and help them to guess good places to dig, which guess may be consciously or unconsciously recorded by the instrument.[1] But in view of the fact that, generally speaking, the rocks below ground water level (say 30 feet depth at most), are saturated with water, it can hardly be believed that the rod can pick out what are known as veins of water, which are really merely more pervious places where the water will more readily flow, and be pulled by them, and not be strongly pulled by the general mass of water. The same thing applies to oil. There is more or less organic, oily, matter in most rock, especially black shale. Mr. Wood, for instance, made an analysis of a sample from the Assyria well at 1575 feet, under the direction of M. A. Cobb, in the laboratory of the Lansing high school, which, though it is only a student analysis, will illustrate the point. Others will be found in the coal report, Volume VIII, part 2, p. 105. It is as follows:—

Analysis of shale from 1575-1700 of the No. 2 Assyria well. Oct. 22, 1903.

Moisture	6.595%
Volatile carbon (largely oil)	6.025
Fixed carbon	3.95
Ash	83.435
	99.985%

How could a body of oil make itself felt through a belt of rock over 300 feet thick and so saturated with oil and gas as this, merely because it happened to be in a more pervious rock which would more readily yield it?

The Assyria well went through the Dundee, but no oil to speak of was found. I did not expect it. A strong brine peculiarly free from sulphates (Mr. Ware wrote in a letter that he thought he detected a trace of barium spectroscopically, which would account for the absence of sulphates), was found, whose analysis was as follows:—

Ann Arbor, Mich., Oct. 31, 1903.

Mr. Alfred C. Lane,
State Geologist,
Lansing, Michigan.

Dear Sir.—We have just completed the analysis of the salt brine sub-

[1]Remarkable successes have been reported to me. For instance, for Jacob Wood of Farmington, now living one mile from Grand Ledge; also for C. D. Woodbury of Lansing.

mitted to us by you, and find it contains strontium, bromine, and lithium (spectroscope anal.). A 40 cc. sample contained 1.044 grams CaO; .510 grams MgO; and 6.9482 grams chlorine (in form of chlorides).

Very truly yours,
Chemical Laboratory, U. of M.,
Elmer E. Ware.

Mr. Alfred C. Lane,
Lansing, Mich.

Dear Sir.—We beg to report the following analysis of the sample of brine received from you, from Assyria, Michigan:—

Gravity	24° Baume
Bromine	0.11%

We have no means of determining the potash. This being a very difficult matter to obtain on account of the presence of so much sodium.

Yours truly,
(Signed) THE DOW CHEMICAL CO.,
Oct. 24, 1903. Jas. C. Graves, Supt.

Of course, the believer in the divining rod said that the oil was there but farther down, in the Trenton, and I advised the secretary of the company to go ahead down to the Trenton, because they were a good deal over half way down, and they might as well make the test thorough while they were about it, in accordance with Prof. Blatchley's remarks.[1]

The one thing that I would urge with all my power upon those who want to take a venture with nature by testing for oil, is that they write to me or some other competent person, find out how far they are likely to have to go to meet the various oil bearing horizons, and how much water they are liable to meet, and accordingly how many times they will have to case, and reduce, and decide before beginning how deep they propose to go before quitting, and begin with a hole large enough. Otherwise, before they have reached the Trenton, if that is their goal, they may have so much water and so small a hole that progress becomes practically impossible; a very unsatisfactory conclusion. It is much better to begin with a little too large a hole than a little too small, as there are a number of heavy flows in Michigan strata.

Then if they want to use divining rods or similar machines or spiritualistic media, to precisely locate their hole, which I do not pretend to be able to do, it is at their own expense, and they will at least have the satisfaction of finding out whether they are right or not.

I may, however, say in general, that so many holes have been put down in Michigan with such ill success, that testing for oil is no enterprise for people who have not money to spare, and that to test for oil and gas, planning only for a single hole, is about as absurd as for a farmer to organize a company to put down on his place one test hole for coal. The successful coal companies have put down holes by the hundred, only a small minority of which have shown workable coal. The state will be very fortunate if the results are no worse in the matter of oil and gas.

The following remarks of Prof. Blatchley are applicable equally to

[1]Next page.

Michigan, with the exception that a boring as far as the Corniferous (Dundee) may reveal whether or not the structure is favorable:—

"Shallow Bores in Central-Southern and Western Indiana.

"Investigations carried on during recent years in the central-southern and western portions of Indiana, and records of many bores which have been sunk in those regions, have led me to believe that the majority of drill holes sunk there in in search of gas or oil failed to reach Trenton limestone, the rock formation which produces the most of the gas and oil in this state. This failure to sink the bores deep enough was due to several causes, chief among which is the great difference in the strata overlying the Trenton limestone in these portions of the state from those overlying the same formations in the main gas and oil-producing areas. In the latter areas the Niagara limestone of the Upper Silurian age and the Hudson river limestone and Utica shales of the Lower Silurian, are the only formations to be pierced by the drill between the drift or surface and the oil and gas-bearing Trenton. In the central-southern and western portions, especially the latter, a number of formations which are wholly absent in the main gas and oil field intervene between the surface and the top of the Niagara limestone. The drillers employed during the gas and oil excitement of 1887 to 1895, to sink the bores in these regions were, for the most part, from the gas fields. Their knowledge of geology was small, and in many instances, after passing through a shale which resembled the Utica, and which they doubtless thought was that formation, they called the underlying rock "Trenton limestone," and soon abandoned the bore as barren. The shales which they had pierced may have been any one of a half dozen carboniferous shales, or, what is more likely, the black Genesee shale, no one of which occurs in the main gas field.

"In a number of instances in the southwestern counties, the Corniferous limestone, which in places is oil and gas bearing, was not even reached, though it lies 900 to 1,200 feet above the Trenton. Wherever a bore was thus abandoned without reaching the Trenton, all the money spent was wholly wasted, there being neither negative or positive results. Moreover, much territory was condemned as non-productive without being given a fair test.

"If the earlier bores had of a certainty reached Trenton and proven barren, then negative evidence would have been available. The one fact which I do wish to impress upon the citizens of the regions mentioned, is that much of their territory has not been properly tested. Another and more important reason for the statement is to induce companies who sink future bores to see to it that nothing stops the drilling before the Trenton is reached, or, rather, before that formation has been pierced at least 75 feet. Beyond that depth there is little probability of finding either gas or oil. A contracting driller of experience can easily and without great expense case off any salt water which may give him trouble. An accurate record of the thickness of each formation passed through, together with a small vial of the drillings of each, will aid much in determining the horizon which the drill is piercing at any depth, and such records and samples should always be kept."

Another important feature in testing for oil and gas (or in fact anything), is to have enough capital to give a proper test. A weakness of many, if not most, developing companies is that the stock is sold so low

that after the promoters' and organizers' stock is taken out and selling commissions subtracted and allowance made for the fact that not all the treasury stock will be sold, there is not enough working capital to really do much, even if there are no salaries to the officers. Mr. F. A. Cook of the Niles Star was good enough to keep a careful record of a well drilled at Niles, by the Niles Oil and Gas Co., the record of which is given below. The business record of the company will also be found in the files of that paper for March and April, 1903, (see especially issues of April 6, 11, and 14), but as it is not geological, even though there may appear to have been something subterranean about it, it will not be fit to introduce here. The only interest the geologist, as such, has, is in noting that explorations on that basis are not satisfactory to anyone. There has been no exploration of the Trenton in the southwestern part of the state, with the possible exception of one hole at Dowagiac.

Southwestern Part of the State.

This district was discussed and a sketch map given in the annual for 1901, and contours of the base of the Devonian black shale given. The

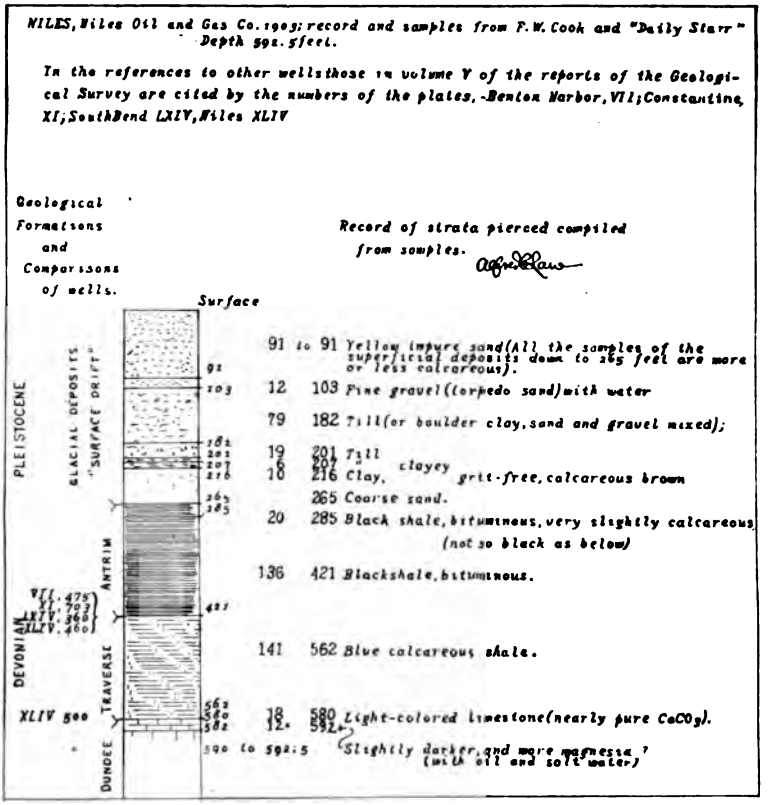
NILES, Niles Oil and Gas Co. 1903; record and samples from F. W. Cook and "Daily Star"
Depth 592.5 feet.
In the references to other wells those in volume V of the reports of the Geological Survey are cited by the numbers of the plates, -Benton Harbor, VII; Constantine, XI; SouthBend LXIV, Niles XLIV
Geological Formations and Comparisons of wells.
Record of strata pierced compiled from samples.
Surface
91 to 91 Yellow impure sand (All the samples of the superficial deposits down to 265 feet are more or less calcareous).
12 103 Fine gravel (torpedo sand) with water
79 182 Till (or boulder clay, sand and gravel mixed);
19 201 Till
6 207
10 216 Clay, clayey grit-free, calcareous brown
265 Coarse sand.
20 285 Black shale, bituminous, very slightly calcareous (not so black as below)
136 421 Black shale, bituminous.
141 562 Blue calcareous shale.
18 580 Light-colored limestone (nearly pure CaCO3).
12. 592+ Slightly darker, and more magnesia, (with oil and soft water)
590 to 592.5
PLEISTOCENE
GLACIAL DEPOSITS "SURFACE DRIFT"
DEVONIAN
ANTRIM
TRAVERSE
DUNDEE
XLIV 500

FIG. 8. Niles Well.

anticlinal indicated as running northeast from Grangers, is apparently the Kankakee uplift of the Indiana geologists.

The record of the Niles well is given in the cut above. It will be noticed that the elevation of the base of the Devonian black shale (the Corniferous or Dundee horizon is within the next 200 feet below) agrees with the map fairly. This well was on the Baumann farm, about a mile west of Niles. The elevation is probably about 660 A. T.—at any rate between 646 and 680 A. T.

Of this well a proper record has been kept (thanks to Mr. F. W. Cook), and returned to this office.

The following data on this district have been gleaned from newspapers and correspondence. A well at Dowagiac was recorded in Volume V of our reports, Plate XVI to 1760 feet. An interesting editorial in the Dowagiac Herald (9—18, 1903), says that it was continued to 2,200 feet by a stock company, i. e., probably to the Trenton and later put down 500 feet or more by Mr. Beckwith, and encountered only salt water, no oil, but on application to the Beckwith estate, we are informed that the record of Volume V is all there was. A good record of this well would be of great interest. We may summarize as probably:—

DOWAGIAC.

Pleistocene.		
Surface, sand, clay, till.....	200	200
Coldwater.		
Blue shale	82	282
Berea or Bedford horizon.		
Red shale (land surface belonging to Antrim?)	12	294
Antrim.		
Blue shale and sandstone.....	346	640
Brown and black shale.....	125	765
Traverse.		
Dark blue, shaly limestone.....	110	875
Dundee.		
Light limestone, not dolomitic. Salt water	125	1000
Monroe.		
Gypsiferous dolomites (anhydrite).....	325	1325
Niagara.		
Light colored dolomitic limestones.....	345	1680
Lorraine and Utica.		
Blue shale (possibly Rochester shale)....	40	1700
Dark limestone	60	1760
(Uncertain.)		
Shales, blue, black, and calcareous, probably to	440	2200?
Trenton and Lower strata.....	500	2700?

This is a little different from the division in Volume V.

The Umholtz Oil Co., Geo. S. Green, President, bored a well on the Umholtz farm about 8 miles north of Niles and 4 from Buchanan, striking through black shale into oil and gas at 618 feet, stopping at 620 (or 625) feet,[1] close under black shale (amount unknown).

They started about Oct. 20th,[2] and were down to 250 feet Nov. 12. By Dec. 1 they were down to 565 feet. At 138 feet it was reported that they went through 7 feet of what proved to be dolomitic pyritic rock. The brine, which followed the oil was analyzed at Northwestern University.

WHITE PIGEON.

Near White Pigeon a well was put down[3] by the White Pigeon Oil and Shale Gas Co., cased as follows:—

140 (?)	feet	10 inch	
220	feet	8 inch	Total, 360
345	feet	6 inch	Total, 705

It was shot at about 765 feet, July 15, without effect. It was down 250 feet on June 19, and was drilled about 800 feet in all. The last 80 feet were probably the Dundee (not Trenton) limestone.

I have to thank the treasurer, Mr. Ed. Roderick, for a careful and complete record and set of samples.

Elevation about 10 (?) feet above Lake Shore and Michigan Southern station at Constantine or about 800 feet A. T. Compare the well at Constantine reported in Volume III, Part 1, p. 93, and in Volume V, Part 2, Plate XI. The location is near the northwest corner of the northeast ¼ of Sec. 22, T. 8 S., R. 12 E.

Pleistocene.

Sample 1. Quicksand, fine silt.....	120	120
Sample 2. Gravel, ¼-inch pebbles (limestone, chert, quartzites, dark traps)....	20	140
130 feet of 10-in. casing shutting off fresh water.		
Sp. 3. Clay, blue calcareous.....	42	182

Compare surface to 93 or 136 feet in the Constantine wells.

Coldwater.

Sp. 4. Shale, blue non-calcareous.....	31	213
Sp. 5. Quicksand.....	28	241

Calcareous and from the varied character of its grains, evidently a glacial sand, which must come in from some vertical fissure traversed by the drill, and yet is peculiar as being in very nearly the horizon of the Berea grit which yielded a strong brine and gas from 283 to 383 in one of the Constantine wells, while in the other it seems to have been represented by 15 feet of red shale, from 286 to 301, while in this well it is not to be recognized at all. This variety in record is probably due to an unconformity at the base of the Carboniferous, and the red shale which

[1] Niles Star, Dec. 12 and 14, Letters, Nov. 12 and 18, Buchanan Record, Dec. 15, 18, 1903, Feb. 2, 32, 1904, "Soo" Ev. News, 3/1/1904.
[2] Buchanan Record, 10/16/1903, Dec. 1, 1903.
[3] Saginaw News, 7/15/1903; Niles Star, 6/19/1903; Constantine Adv.-Record, 7/8/1903; Free Press, July 15, 1903.

appears in various records in this corner of the state may be due to the weathering and oxidation of black and green shales beneath an old land surface.

8-in pipe driven into No. 5, 9 ft., i. e., about 220 ft. in all.		
Sp. 6. Shale, dark blue, probably in part Antrim, belonging with the next division	224	465

DEVONIAN.

Antrim shale.

Sp. 7. Black shale.....	108	573

This apparently corresponds to the base of the dark shales at Elkhart between 375 and 350 feet down, and in the first Constantine well record the red calcareous shale immediately underlying is counted in, and 211 feet of shales given between 492 and 703 feet. Corresponding horizons are found about 82 feet deeper at Constantine.

Traverse formation.

Sp. 8. Red calcareous shale.....	32	605
Very calcareous, gritty with a few large grains of sand and some crinoid buttons.		
Sp. 9. Soft blue limestone.....	78	683

This formation was apparently not separated off in the Constantine records, but its base and the top of the Dundee is probably nearly marked by the brine and sulphuretted hydrogen which occur at 790 feet and correspond to the horizon of the "salt sand" from 696-711 feet here. The red, gritty shale at the top may also mark a time between the Traverse and Antrim as here developed, when there was a land surface here. The paleontogist Schuchert[1] assumes that there was a neck of land here at about such a time, and the more recent Niles and Dowagiac wells show a greater thickness of blue calcareous shale with no red shale mentioned, while from Coldwater and Elkhart no Traverse is reported. The Niles well in Volume V gives us from 415 to 500 feet very similar strata.

Dundee.

Sp. 10. Missing. Said to be similar to those below	13	
Sp. 11. Limestone, very white, clear, fiercely effervescent in acid, leaving a little quartz sand residue.....	15	
"Salt sand," here a brine was struck which filled up the hole about 400 feet, no casing done when the well was shot.		
Sp. 12. Five samples, all yellowish, fiercely effervescent limestone with a little quartz and microcline sand and more chert	45	
At bottom, "oil sand".....	73	756

[1] American Geologist, September, 1903, p. 149.

Sp. 13. Limestone; record says "blue shale," but sample is a coarsely chipping, fiercely effervescent, somewhat darker limestone, stuck together with gypsum, possibly from the brine.....	7	763

The well was torpedoed here, but as it was not a dry hole it was not a fair test.

An interesting thing is the irregularity of the Berea grit shown by this and adjacent wells. I think that a well might possibly strike gas in this formation, enough to be valuable, if placed so that it could be used near by.

The base of the black shale is at about 227 A. T. At Constantine it is about 137 A. T. At Elkhart it is perhaps about 205 A. T., but the record and elevation are uncertain. At South Bend the base is at 375 feet A. T. It is apparent that the dip from this well to Constantine is pretty sudden and that the contour of the figure below, repeated from the annual for

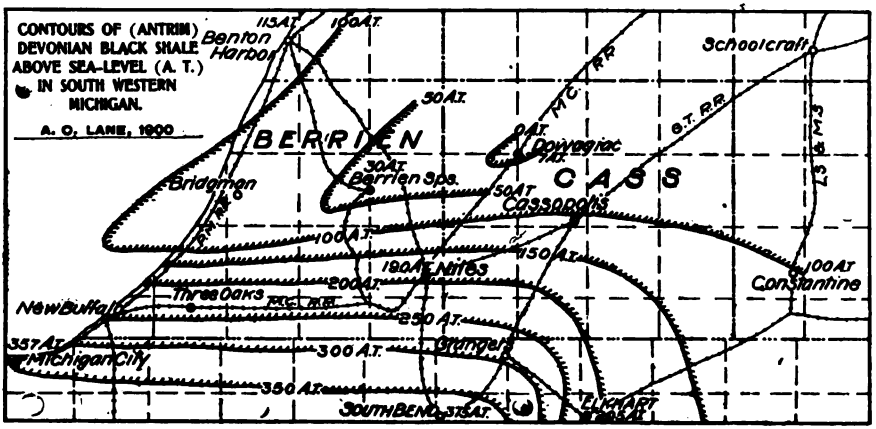

Fig. 10. Sketch of contours of the base of the black shale. [Repeated from annual for 1901 and not quite right.

1901, should continue on further to the east instead of turning sharply south, and then if the Elkhart record is right, there must be a sharp drop (fault?) along a line running between South Bend and Elkhart, and passing east of Constantine and White Pigeon. One or two more wells in the south part of St. Joseph county, ought to cost less than $2.00 a foot for less than 1000 feet and might develop something of interest and value. There has been some talk of a well at Sturgis. I do not, however, advise planning to go down to the Trenton until we know a little more about the lay of the upper formations.

At Granger, just over the line in Indiana, a well was put down over 350 feet.[1] The Bridgman Oil and Gas Company,[2] has started to put down another well at Bridgman. The old well put down over 20 years ago, went about 100 or 175 feet to rock, 50 to 130 feet in rock, probably the Devonian shales (compare the Berrien Springs record), when a pocket of gas which burned some time was struck. The new well has the following

[1] Niles Star, 6/19/1903.
[2] Benton Harbor News, 9/2/1903; Benton Harbor Daily Palladium, 8/31/1903. South Haven Sentinel, 7/2/1903.

record, most of it reported through the kindness of R. J. Stahelin and G. W. Bridgman.

BRIDGMAN.

"Record of the Bridgman Oil and Gas Co.'s well, located about 40 rods south of depot, on ground about 3 feet lower than railroad track, i. e., 636 A. T.—May, 1904."

	Feet.	Feet.
Pleistocene.		
Sand	3	3
Clay, sticky	100	103
Sand, fresh water	5	108
Clay, blue	50	158
Sand, some fresh water	5	163
Clay, blue	40	203
Sand, fresh water	20	223
Gravel, cement	5	228
Clay, blue, waxy	30	258
Coldwater.		
Clay (really shale), big break	50	308
Antrim.		
Brown shale, gas near top, scum on water after striking gas	200	508
Dundee.		
So called Trenton, bastard	5	513
Samples 520 to 700, limestone with echinoderm fragments, quick effervescence.		
Salt sand	25	538
Brown sand, salt water here rising nearly to the top	25	563
Trenton, porous, drilled nice	200	763
Salt water at bottom of this 200 feet, with traces of gas above.		
Monroe.		
Sample at 768 a gypsiferous dolomite.		
Water stands 600 feet deep in the well	5	768
Total		768

"The above report was given me today by one of the workmen who is still here. It may not be quite accurate, but think it is as near correct as it can be had, as there was no record kept while drilling."

A company was also organized to operate near Galien, but Mr. Loomis, who was also connected with the Niles Oil and Gas Co., above referred to, was interested in it, and nothing seems to have come of it. Mr. J. J. Cal-

lendar, the same who located the Assyria well with his "instrument," is reported to have located the oil.[1]

The Assyria well, 917 A. T., might be treated in this connection, though it is in some respects more allied to those of the central district. It is the one I referred to as having been located by a modified divining rod. Through Mr. Geo. D. Conner and J. J. Callendar I have received a good set of samples and I also visited the well to get the elevation and temperatures. It was to be put down further in the spring of 1904 and the record is postponed, so that it may be given complete. The Berea—Bedford red shale was from 1400-1450 feet, and the Traverse from 1810 to 1875 feet.

About 1½ miles east of the corners another well was put down in 1899, of which, in spite of various endeavors, I never was able to get a satisfactory record. I did, however, meet the driller, Mr. John Brogan, at Mr. Stearns' well in Ludington, and obtained some of the data from him. The bottom of the black shale, top of the Traverse or Dundee, was at 1875 feet. This is quite a little lower than the other well,—about 870 A. T. on Sec. 14, T. 1 N., R. 7 W.

The Milan well reported in 1901 was deepened and the record now runs from samples as follows:—

MILAN.

Pleistocene	130	130
Traverse.		
Blue limestones and shales	168	298
Dundee.		
Limestone	97	395
(About 100 feet less in depth than at Britton.)		
Monroe.		
Lucas.		
Dolomite, gashed or acicular[2] at 395, 415, etc.	35	430
Gypsiferous dolomite	25	455
Gypsum, mainly	80	535
Sylvania sandstone, pebbly at base	288	823
Tymochtee?		
Calcareous shale	7	830
Dark, oily dolomite, H_2S water	15	845
Cherty dolomite	55	890
Dolomite, blue, with mineral water at		890
With some black specks mixed	100	990
Blue clay shale	5	995
(Compare Britton 1015.)		
Dolomite (at 1025 to 1100 anhydrite, also at 1210 and 1275)	305	1300
Red, then blue shale	100?	1400
Brown, oily dolomite—fine laminated	75	1475
Dolomite	65	1540
Rock salt	5	1545

[1]Port Huron Times, 6/6/1903; Detroit Journal, 5/16/1903; Buchanan Record, 12/15/1903.
[2]It has recently been suggested by Kraus in Science that these gashes are due to dissolved crystals of celestite.

Niagara?

Dolomite	98	1643

Of a well on the farm of Uriah Arnold near Clinton, Sec. 2, T. 4 S., R. 3 E., we have learned only that they struck little if any oil, but a strong brine at about 1000 feet.[1]

This seems to be as far south as the rock salt occurs and it is interesting to note that here, as in Ludington and other points, the rock salt at its greatest extent occurs close to the base of the formation, and the higher beds occur only near the center. The total thickness from the base of the Sylvania to the base of the rock salt is 722 feet, the brown, oily dolomite above being nearly the same as at 1500 to 1550 feet at Britton, and the Niagara, the typical white Guelph coming immediately below.

Around in that region shallow wells, as already remarked by Sherzer and myself, are very likely to find small amounts of oil or gas of local value only. At Britton, where a deep well was reported on in 1903, on the lot of John Wiggins a well for water at 90 feet struck a pocket of gas, the glow of which when lighted, could be seen in Tecumseh. How much was wasted before it was controlled I do not know, but the pressure is said to have increased since,[2] from 35 pounds per square inch to 41, which is probably about the hydrostatic head. I would again call attention to the probable value of such modest wells, their relatively short life, and the possibility that in the ordinary way of accidentally striking them, thousands or even millions of cubic feet of gas may be wasted before they are controlled.[3]

In this connection it may be well to introduce a comparison of nearly equivalent formations and names in Michigan, Ohio, and New York, as used by Prosser[4] and Clarke and Schuchert.[5]

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[1]Detroit Free Press, 6/24/1903.
[2]Adrian Times, 6/22/1903, Free Press, 5/27/1903.
[3]Such a blow out of gas was struck at Halfway near Detroit at a depth of 460 feet, News and Free Press, 4/9/1903.
[4]The Nomenclature of the Ohio Geological Formations, Journal of Geology, Sept.-Oct., 1903, Vol. XI. No. 6, pp. 520-521.
[5]American Geologist, Feb., 1903, p. 118.

COMPARISON WITH THE NEW YORK SERIES.—CLARKE & SCHUCHERT.

Era or system.	Period or group.	Age or stage.	Prosser, Ohio.	Michigan.[1]
Cambric or Taconic	Georgian	Georgia slates.		Lower Keweenawan.
	Acadian	Potsdam sandstone		Upper Keweenawan.
	Potsdamian			Potsdam or Lake Superior.
Champlainic (1) (Lower Silurian and Ordovician).	Canadian (3). (Paleochamplainic)	Beekmantown limestone (15).		Calciferous.
		Chazy limestone.		Unconformity.
	Mohawkian (4). (Mesochamplainic).	Lowville limestone (16).	Trenton	Trenton.
		Black river limestone.		
		Trenton limestone.		
	Cincinnatian (5). (Neochamplainic).	Utica shale.	Utica.	Utica.
		Lorraine beds (17).	Lorraine.	Lorraine.
		Richmond beds (Ohio and Ind.).	Richmond.	
Ontaric (2) or Siluric	Oswegan (6). (Paleontaric)	Oneida conglomerate.	Saluda.	Unconformity, erosion.
		Shawangunk grit.		
		Medina sandstone.	Medina.	
	Niagaran (7). (Mesontaric)	Clinton beds.	Clinton.	Niagara (Manitoulin).
		Rochester shale.		
		Lockport limestone.	Niagara.	
		Guelph dolomite.		
	Cayugan (8). (Neontaric)	Salina beds.	Tymochtee.	Salina.
		Rondout waterlime (18).	Sylvania.	Sylvania.
		Manlius limestone (19).	Lucas.	Lucas.
				Monroe.

Devonic	Neodevonic	Chautauquan (14)	Chemung beds	Black Hand	Lower	Marshall.
					Napoleon Upper	
			(Catskill sandstone, (35)	Logan formation	Michigan, Lower	Grand Rapids.
			local facies)	Maxville	Maxville, Upper	
				Unconformity, erosion.	*Pennsylvanian.*	
				Pottsville 250±	Saginaw.	
		Senecan (13)	Tully limestone	Ohio shale	Antrim shale.	
			Genesee shale			
			Portage beds	Bedford shale		
			(Naples beds	Berea grit	Berea grit.	
			Ithaca beds	Sunbury shale	Berea shale	
			Oneonta beds.	*Mississippian Carboniferous.*		
			local facies	Cuyahoga formation	Coldwater.	
	Mesodevonic Paleodevonic	Erian (12)	Marcellus shale	Olentangy shale	Traverse.	
			Hamilton beds		(erosion in southwest part ?)	
		Ulsterian (11)	Esopus grit (24)	Columbus	Dundee.	
			Schoharie grit	Sandusky		
			Onondaga limestone			
		Oriskanian (10)	Oriskany beds.			
		Helderbergian (9)	Coeymans limestone (20)	Unconformity of erosion in Ohio and Michigan.		
			New Scotland beds (21)			
			Becraft limestone (22)			
			Kingston beds (23)			

[1]Leaders connect the more or less precise correlations. The correlation of the Marshall with the Chemung and Catskill is lithologic and physiographic, not paleontologic.

Port Huron District.

In regard to this district, C. H. Gordon has made the following report in addition to that which he prepared last year. We have also records from the Port Huron Salt Co. and the Diamond Crystal Salt Co., which will find an appropriate place in treating of the salt formations, and in connection with the Detroit river wells.

Valley Center, Mich., Aug. 9, 1903.

Dr. A. C. Lane,
Lansing, Michigan.

Dear Dr. Lane.—Two wells have been put down in this vicinity, reports of which interested me, and I made inquiries, the results of which I send you herewith.

1. Brown City well. This well was put down recently to secure an adequate supply of water for the use of the village. It is located near the depot (Elev., 812 A. T.)[1] and stopped in sandstone at a depth of 227 feet. The thickness of drift passed through was 180 feet, consisting of clay and "hard pan" to within a few feet of the rock. The space between the "hard pan" and rock was occupied by gravel as at Valley Center[2] and elsewhere, but was not so full of water, which was found in abundance in the sandstone below. This shows that the drift is not so thick here as previously supposed. In our report, the only information we could obtain was to the effect that the Harrington well, located within a hundred yards of the new well, was sunk 212 feet without reaching rock.[3] The papers reported that copper and silver had been struck in the new well. On inquiry I learned that what was regarded as copper was found in the gravel bed overlying the sandstone. It occurred in small particles associated with a white metal taken to be silver, the latter quite rare.[4] My information was obtained from the president of the village board. Water stands within 11 feet of the surface in the well.

2. Graves well. This well is a drilling made for water on the farm of G. Graves, 1¾ miles south and ¾ miles west of Valley Center in the N. E. ¼ of the S. W. ¼ of Sec. 34, of Maple Valley Tp., T. 9 N., R. 13 E. In this well it is claimed that hard coal was struck at a depth of about 114 feet which the drill (a light affair) would not penetrate, being broken three successive times. On losing the drill head the drillers attempted to break up the rock and get the lost drill out of the way by dynamiting, with the result that the casing was broken and the well lost. A second and third attempt, each at a distance of six to ten feet from the first met with the same result. The fourth hole is now down to a depth of 104 feet but no drilling is being done owing to a press of other work. The record of the drilling as given me by Mr. Graves, is as follows:—

[1]Report on Sanilac county, p. 5, Vol. VII, Part 3, Mich. Report.
[2]Ibid, p. 11.
[3]Report on Sanilac county, Vol. VII, p. 10.
[4]It may have been bronze and white mica.

1.	Clay	about 70 feet
2.	Hard pan	about 30 feet
3.	Gravel with water coming to the top	about 7 inches
4.	Soapstone	about 4 or 5 feet
5.	Stone, hard to drill	about 8 or 9 feet
6.	Gravel with water	4 inches
7.	Hard coal. Very hard to drill. Could not make more than 3 or 4 inches a day. Broke the drill each time. Penetrated about 10 or 11 in.	
	About	114 feet, 10 in.

Mr. Graves says there has been no hard coal about the place for a long time and he is of the opinion that it could not have been put in from the top. Each night the hole was covered and a heavy weight put over it. No motive can be suggested for "salting" the well. The loss of the wells rests entirely on the driller who contracted to furnish a satisfactory well at $1.00 per foot. In one of the holes he says a coal seam was struck somewhat higher than in the others but the main bed, if such it is, was found at the same level. I send you specimens of the coal brought up by the drill. There seems to be no question of its being anthracite.

I give you the facts as he gave them to me. My impression is that someone is trying to "do" the driller, possibly to even up an old score.

Very truly yours,

(Signed) C. H. GORDON.

Central Part of the State.

It will be remembered that in previous reports[1] I have mentioned anticlinals as probably existing in the central part of the state, and pointed out that one probably passed through Saginaw (Wiley Brothers' well is near the crest), but was not able to give its course. The prosecution of coal mining and exploring makes it more and more probable that the Saginaw seam, 180 to 190 feet beneath West Saginaw runs up into the same mine at about 155 feet south of East Saginaw. Again, according to the reports of Mr. Chas. Page, the well of the Monitor Oil and Gas Co. on the S. W. ¼ of the S. W. ¼, Sec. 26, T. 14 N., R. 4 E., considerably higher (605 A. T.), than the South Bay City well,[2] 582 A. T., ran some 30 to 40 feet less depth.

The Upper Marshall is said to have been from 800 to 930 feet. A sample of fine grained, red sandstone at 1050 looks like lower Marshall. The tools got stuck at 1700 feet, but this and other records bring out clearly in a section prepared by Mr. Cooper for his Bay county report, an anticlinal between Bay City and Midland. It is probable, therefore, that the Saginaw anticlinal ran rather nearly north, passing 3 or 4 miles west of Kawkawlin, at which town corresponding strata are much higher than in Bay City.

[1] Vol. VIII, Part II, p. 176, Annual Report for 1901, pp. 211-237.
[2] Annual for 1901, p. 234.

LIVINGSTON COUNTY.

There have been pronounced signs of oil and gas discovered and quite an oil excitement recently in the northwestern part of Livingston county[1] near Fowlerville. I have also some records of a well near Morrice, which, though incomplete, are interesting, and seem to indicate a well marked anticlinal at least down to the Berea grit. This occurs according to J. J. Mason, at Columbiaville (764 A. T.) at 1500 feet, 90 feet of sandstone full of brine; at Flint (723 A. T.) possibly at 1200 feet depth; at Blackmar (610 A. T.) at about 1675 feet depth. On the other side of the basin it is absent, but its horizon apparently occurs at Jackson at 1400 feet depth, and at Assyria (917 feet A. T.) at 1400 to 1450 feet depth and at Charlotte at 1680 feet depth. But between we do not find the Marshall and Berea deepening as might be expected. It is possible that the deepest well at Lansing reached it at or before 1400 feet.

There was a well put down by C. W. Gale in the 1860's close to the Looking glass river (850 A. T.) on Sec. 25, T. 6 N., R. 2 E., of which we can get a record only from memory, that it was about 1100 (1135) feet deep, that at the bottom a strong brine was struck of which a sample was sent to A. Winchell, that it did not smell of sulphur, that this brine flowed and that a little oil used to show on the river, that much black shale was traversed and also a lot of "blue clay," The first casing was 45 feet to rock, which was sandrock. At about 100 feet a second casing was put in and at 600 feet a seed bag was put in so as to use the top water when it was decided not to use the brine. The top was drilled wet and water was never over 10 feet from the top at any time.

This sort of a record with so much blue and black shale suggests the Coldwater and Berea or Antrim shale, as does the Durand well given in Volume VIII. But if this sandstone and brine is the Berea there can be but little doubt that that of Jason and Shumway is also, who put down a well northwest of Fowlerville on the farm of Mr. Grill on Sec. 17, T. 4 N., R. 3 E., about 1000 feet A. T. The record of this is given as follows:—

Well on Sec. 17, T. 4 N., R. 3 E., about 945 A. T.		
Surface to rock (8-in. drive pipe)	95	95
Slate (at 120 feet oily at the house)	35	130
Shale (gas at 155 feet)	63	193
Gray sand (dry well from 200-600 feet)	25	218
Brown shale (gas at 380 and 600 feet)	382	600
8-in. hole for 587 feet, cased at that depth with 5⅞-in. casing.		
Coarse gritty sand with salt water	200	800
As analyzed, filled the well, and slowly oozed out in spite of a plug, with bubbles of fuel gas, and a temperature of 65°.		
Black shale	20	820
Brown shale	150	970

Though full of salt and plugged there was a constant leakage of gas. This coarse sandstone full of a very strong and pure salt brine at so shallow a depth, must be either the Marshall or the Berea. But the Marshall

[1]Free Press, 5/17/1903; also 5/23/1903; 5/30/1903; Fowlerville Review, 10/16/1903; South Lyons Herald, 5/15/1903; Detroit Tribune, 5/26/1903, with photographs; Lansing Journal, 5/23/1903, 11/4/1903.

is not usually associated with black shale, while the Berea is. In that case there must be a marked anticlinal uplift, which also probably includes the wells at Durand and Howell, which were interpreted in Volume VIII, Part 2, as the Coldwater. The recent well at Holly showed apparently mainly Coldwater shales. What becomes of the Marshall is quite a question. It may be that this uplift, like others, antedates the coal measures, but not the Grand Rapids series, and is connected with the break between the Pennsylvanian and Mississippian systems, and that the rocks between the coal measures and the Coldwater were in good part either not deposited or eroded away. The sandstone at the base of the coal measures and Marshall are hardly distinguishable. The prevalence of brown and black shale in these wells is not unfavorable for oil.

If this is right, the anticlinal probably runs in a northwest and southeast direction from Laingsburg. Moreover, we may infer that coal is most likely to be found on its northern and southern flanks.

Beside the well above mentioned, two relatively shallow wells have been put down about 6 miles away on the Henry White farm on N. E. ¼ Sec. 6, T. 3 N., R. 4 E. The shooting of the second was witnessed by my assistant, Mr. W. F. Cooper, on Nov. 3, 1903. It was down 50 feet on Oct. 6. It is 40 rods south of an earlier well which is said to have had salt water. The record as given, is as follows:—

Fowlerville Oil Well.

Two miles south and 2¾ miles east of Fowlerville in the N. E. ¼ of Sec. 6, T. 3 N., R. 4 E.

Pleistocene.		
Clay	30	30
Sand	8	38
Gravel	2	40
Sand	6	46
Blue clay	28	74
Sand	30	104
Gravel	2	106
Sand and gravel	22	128
Sandrock	8	136
Blue shale with oil and gas, the flow being about ½ barrel per day	30	166
Dark sandstone at 157 feet.		

All samples 60, 70, 80, 95, 120, very effervescent clay till.

Samples from 60 to 120 I should class as calcareous clay till, and a sample at 157 as a dark sandstone. This well might pump ½ barrel a day.

This may be the best place to insert a reference to the four or five wells at Mt. Pleasant, and two or three at St. Louis, which have been put down to make bromine and salt. Those at St. Louis are 1300 to 1330 feet deep and draw from the same stratum as those at Mt. Pleasant,—the Upper Marshall or Napoleon sandstone, the record of which is in brief:—

MT. PLEASANT.

Surface deposits and glacial till.....	1- 400 ft.
Coal measures with particles of coal at 410-430-560 down to 620.	
Parma sandstone,—calcareous and with 10 to 20 ft. of limestone.....	810- 840
(There was plenty of water and may be drinkable,—something like the Harrington House water at St. Louis.)	
Maxville limestone,—as at Bayport.....	970-1050
Michigan series, with gypsum as at Alabaster	1050-1408
Marshall sandstone	1408-1550

The temperature varied from 67.6 degrees at 1450 feet to 49 degrees at 200 feet. The rate of increase is not absolutely uniform.

In closing my notes on the subject of boring for oil and gas this year, I take pleasure in referring to the elaborate reports issued by Prof. W. S. Blatchley, State Geologist for Indiana, from Indianapolis and the auspicious resumption of the publications of the Geological Survey of Ohio under E. Orton, Jr., by Bulletin No. 1, containing a report on the occurrence and exploration of petroleum and natural gas in Ohio, by J. A. Bownocker, published at Columbus, Ohio. This contains in Chapter V, a good review of the theories of the origin of oil and gas, which will save my going into the subject now. I may also say that so far as lower Michigan is concerned, oil and gas seem to arise from the decomposition (very likely bacterial, most decay is) of buried animal and vegetable matter.

If the deep well at Rapid River strikes oil or gas down in the preCambrian, I shall begin to believe there may be something in the theory of inorganic origin of petroleum as applied to the commercial product.

PEAT.

Dr. Rominger closes Chapter II of Volume III of these reports with the following prophecy, "fuel is too cheap yet, but the time will come when peat will be appreciated at its true value." With the exhaustion of our forests, which has caused the development of the coal, cement and brick resources of this state, the time seems at hand for the fulfillment of this prophecy. The problem of the utilization of the peat is one for the mechanical engineer as well as the geologist. But fair questions for this board to help solve pertain to the properties of the different kinds of peat as they lie in the bog. How stringy is it and how does this factor depend upon the plants that made it or upon the variations of water level? What liability is there to be logs of wood, stumps, and other obstacles to easy working scattered through the swamps, and what kind of swamps are most free? What is the effect of a certain admixture of mud and silt? Suppose a peat thoroughly dried, how much will the different kinds reabsorb from the air (for they will take up some)? These are some of the questions upon which we have obtained data. I had hoped for a report ready for this year. I think we shall certainly by next year have something worth while to add to our brief statement in the 1902 report.

Prof. C. A. Davis has been at work for us, and writes as follows:—

"I had a chance to spend some days in the camp in Roscommon county where the Bureau of Forestry party is at work and availed myself of it and am very glad I did so, for it took me into a country where peat bogs are really a feature of the surface geology, and not simply an incident or accident. I found there that the plants are the same that occur at Ann Arbor in bogs and that they occur in the same relationship to each other and to the water level and the shade that they do there, and that the bogs pass through the same stages of development, reaching a climax which is practically permanent so long as the water level is constant or rising only as fast as the bog builds up, but if anything occurs to cause decided elevation or depression then a change occurs, which, if the water level is raised, is in the nature of a rejuvenation, in which the bog goes back to the marsh or even pond stage, and begins over again, or if it is lowered then the bog plants are crowded out by more aggressive species from the higher land around. Thus around the camp where I stopped, were numerous bogs which had been rejuvenated by the building of dams by the lumbermen, and it was easy to see that the rising of the water level had killed out the old plant covering and had given the sedges and grasses a chance to come in again and there were numerous "hay marshes," as they call them up there, which had evidently been cut out of the older cedar and tamarack swamps by fire, the peat burning down to the level of the ground water, after which the same sedges and grasses which build out over the lakes here have gained possession and have started in a new cycle which will progress from sedge to grass, to heath-sphagnum, and finally to cedar-spruce-tamarack and possibly to elm and ash swamp. In my studies of the bogs north, I have been interested to see that the plants which south all huddle in the bogs and keep at about the same distance above water level, are, as we go north, separated by degrees, until it is practically certain that several of them are not bog plants at all in the north, but occur only on the deeper levels of rather poor soils, and even some species, which botanists are inclined to call bog plants exclusively, do not get down into the bogs, but are simply confined to their margins and the indications are from the analogy of the plants which get away entirely from the bogs, that most if not all of the bog plants down in this part of the state, get into dry situations to the north and give place to other species from farther north in the bogs. This is an interesting discovery from the point of view of the ecologist, and from our point of view as well, for it opens up a way to form a hypothesis that the northern bogs grow more slowly, or possibly more rapidly than the southern. I think it is likely that I shall decide that it is more rapidly, for if the broad leafed shrubs and trees cannot get into the bogs until a relatively great elevation of surface has occurred, then sphagnum, which is probably a rapid peat maker when once it is established, has the longer chance to grow and build before the higher plants shade it out. On the other hand, if it is true that the higher plants make the most rapid accumulations of peat then the northern bogs would grow more slowly. At any rate it seems certain that the more northern the bog the longer it will remain open so long as the water levels do not change. It is also possible to tell the present condition and stage of development of a bog by the flora of the surface of it, but evidently from the foregoing, it is not possible to tell anything about the quality of the peat, for present conditions may be the result of very evanescent conditions which have not been in existence but a short period of time. So much for

this side of the investigation, which is one of much interest. The region south of Roscommon which, by the way, Leverett has mapped with some care[1] is full of extensive peat bogs, probably of varying depth, but some must be quite deep. The aggregate area is large and from the configuration of the country and the nature of the soil the peat must be of good quality. I did not bring samples back as I had my grip full of stuff and had such long distances to travel by carriage, but they can easily be obtained if wanted. The peat I examined up there was mainly fibrous and not thoroughly decomposed, a kind hard to handle as the Capac people are finding out; it does not cohere in the compressors, so that the briquettes are not durable. I may say that seems to be true of all the northern peats I have examined. I have worked up the Ann Arbor R. R. to Frankfort, and looked around quite a good deal on other roads, and near the railroads there are not many large areas of peat that I have seen. The deposits near Jackson, I went over with Thompson and from Jackson on down the old drainage channel to Kalamazoo and beyond, there is a great area of peat, which is more thoroughly decomposed than that north, and which is also more compact, as would be expected. This grade is of course, higher in ash, but it can probably be put into form for consumption without much compression and possibly by some drying, so it is well worth trying. There seems to be an abundance of this sort of material in the region, and in fairly large areas, but much of it is still covered with bushes and trees so it is not so easy to get at as the open bogs. Thompson says that he went into the Upper Peninsula and prospected a number of bogs but found them full of submerged tree trunks and stumps so that he could not get his sounding rod down in them, and I presume he is right about the matter, since I had the same difficulty in the bogs around Cadillac and in Roscommon county. Such bogs, of course, add materially to the cost of getting the peat out, since they have to be handled individually and cannot be scooped up by machinery. They are having some trouble with such material at Capac, although the amount of it there is not very large. In Roscommon county I learned that in some places where bogs had been cleared, the buried logs and stumps were so thick that when they were logged up and burned down to the level where the land could be plowed, the surface was lowered so that the attempt at cultivation was abandoned because the water stood on the surface and the cultivation plants were drowned out."

Alma, Mich., June 10, 1903.

Dear Doctor.—I herewith transmit copy of notes on peat analyses of samples taken from near Ludington.

No. of samples.	H_2O. %	Sand. %	Dry peat. %	B. T. U.
1, 3, 5 and 7.....	86.5	1.6	11.9	
4	87.0	3.0	10.0	
2	90.0	2.0	8.0	
6	88.0	.....	.....	8633

You will notice that about ten per cent. of the wet substance is combustible matter, and that the amount of sand is very large. Sample No.

[1]See Livingston's map in this report, Plate III.

6 when dried in oven gave 8633 B. T. U., so I calculate a ton of thoroughly dry peat of this quality is equivalent in heating value to an equal weight of beech and maple wood.

Yours truly,
A. N. CLARKE.

Prof. R. T. Jackson of Harvard University made a not profitless trip to some of our chief later paleozoic localities, from which we had hoped for paleontological light. The report has not been received in time for incorporation here.

RELATION TO OTHER ORGANIZATIONS.

Relations with the U. S. Survey have been as close as heretofore not only in coöperation in the topographic survey leading to the publication of the Ann Arbor quadrangle and preparation of three-fourths of the Detroit quadrangle, but also in the continual interchange of information, in the preparation of the Ann Arbor topographic and geologic folio, by Messrs. Russell and Leverett, in the study of water powers, in charge of Mr. R. E. Horton and W. M. Gregory, and the water supply through Mr. W. F. Cooper and M. L. Fuller and Alfred R. Schultz, and in the study of the sedimentary section of the Upper Peninsula by Mr. Alden.

Mr. Chas. S. Prosser, working for them mainly in Ohio, has recently published a classification of the Ohio column[1] elsewhere given, in which he has adopted our term Monroe, after discussion with us and the U. S. authorities, and we expect to use his terms Lucas and Sylvania. I would call attention to a pamphlet recently issued by the U. S. Geological Survey[2] on coöperation with the state surveys.

Another similar pamphlet of interest[3] relates to coöperation in the collection of statistics between the various bureaus.

I endorse the recommendations thereof and repeat my suggestion of past reports that there be more uniformity in the gathering and publication of statistics. Changes in the method of gathering or even of presenting these is a very great detriment to their value. Statistics form a science by themselves, and though, as the paper shows, in many states some statistics are handled by boards which also conduct geological investigations, I am not entirely convinced of the wisdom of this. I think the mineral statistics and reports of inspectors of mines, etc., should be published in connection with the other industrial statistics, though there may be friendly coöperation in gathering information. Mr. Hanna, the present commissioner, has started some very valuable tables which should be kept up continuously and systematically.

I do not think that this board should gather such statistics. There are, however, two other extensions of the work of your board which seem to me more desirable. For some years the Michigan Academy of Science has recommended a biological survey of the state. This has been carried on in connection with the geological survey in a number of states. An abstract of the reasons for, and utility of, such a survey is given by them as follows, and has been the theme of Prof. Newcombe's presidential address:—

[1]Journal of Geology, Vol. XI, No. 6, 1903, p. 519.
[2]Extract from the 22d Annual Report of the Director.
[3]Cooperation and unification in Federal and State Statistical Work, a paper read at the 19th annual convention of the Commissioners of State Labor Bureaus, Washington, D. C., Apr. 28, 1903, by S. N. D. North, Washington, D. C., 1903, pp. 5, 6, 7, XI.

Reasons for a Biological Survey of the State of Michigan, Prepared by the Michigan Academy of Science.

I. States making or having made such surveys.

New York, Pennsylvania, Ohio, Indiana, Illinois, Wisconsin, Minnesota, and California.

Various other states not appropriating funds directly for a biological survey, empower various boards to do such work. Thus the health board of Massachusetts makes biological surveys of rivers and lakes used as water supply for cities.

Michigan, in connection with the geological survey, began a biological survey in 1837, which, for lack of funds, was discontinued in 1840.

II. Reasons for making a biological survey.

1. To add to the sum of human knowledge.
2. To furnish data for nature study in the schools.
3. To furnish data on the past and present resources of the state in timber, fish, game, forage plants, fruits, peat, marl, etc.
4. To furnish a scientific basis for practical work in preserving and replenishing these natural resources. (Forest are to be grown again in Michigan, and peat can be made to reproduce itself. One-half the area of the state is water or land unfit for agriculture, but can be made a source of wealth on account of its forests, fish, and game. The commissioners of fisheries and game in Maine estimate the amount spent in 1902, in that state, by those coming from other states to hunt and fish, at $6,000,000 to $12,000.000.)
5. To secure the introduction of new plants and animals of economic value.
6. To restrict the spread of plant and animal diseases.
7. To furnish data for just legislation on forestry, water-supply, and the taking of game and fish.

III. Lines of work to be followed in a survey.

1. The collection into accessible form of the scattered publications on the plants and animals of the state, and the completion of the examination of the whole state, so that every school and everyone may know the plants and animals of his neighborhood.
2. The study of the habits of plants and animals, their food, their migration, their reproduction, and their beneficial or injurious effect.
3. The study of the relation of plants and animals to soils, to climate, to rainfall, etc., so as to enable one to know where agricultural plants, fruits, etc., may be raised.
4. The special study of rivers and lakes to determine the food of fish and the means of propagating fish in waters now furnishing no support to them.
5. The especial study of the habits and propagation of game birds and animals.
6. The especial study of problems in reforestration of waste lands.
7. The study of the water supply of cities.
8. The especial study of insects, fungi, and bacteria, and the means of combatting pests and diseases, for instance, distribution of malaric mosquitoes.

Granted its advisability, the reasons for its being conducted by the board are three-fold:—

(1.) The precedent of other states.

(2.) The economy of administration, over having a separate board of survey.

(3.) The unifying of the scientific research of *all the higher schools* of the state, rather than having such a survey conducted as it is in some states, solely by the university. If the board of regents of the university were in this state, as in New York, the center of all the educational interests of the state, this argument would not apply.

Feeling that the arguments for a biological survey as above given, were weighty, I favored an appropriation to that end, introduced as a separate bill, which passed both houses though it failed to become a law. My experience, however, with another separate appropriation which *did pass,* to aid the topographic survey, has, as below mentioned, not been entirely satisfactory. The keeping items charged to different petty accounts means much more work, both in my own and the auditor's department, and one great advantage of having the biological survey attached to the geological survey,—the ability to attach a biologist to a geological field party—would very probably involve us in bookkeeping snags. Would it not be better simply to provide in one act for the extension of the work of your board to cover this field, and then to provide separately for such increase in your general appropriation as might be deemed advisable, trusting to your board to apportion the same fairly, or directing that not less than an average fixed sum be expended in certain directions?

The same thing applies in regard to the topographic survey which has been urged by the Michigan Engineering Society as well as the Academy of Science, and was favored by the late Senator McMillan. The utility of the joint topographic survey is unquestioned, and I append Col. Muenscher's report to the Michigan Engineering Society.

Report of Committee on the Topographical Survey of the State.

To the President and Members of the Michigan Engineering Society:—

Your committee on the Topographical Survey of the state would respectfully report that they have done nothing as a body the past year in furtherance of the object for which they were appointed. The indifference with which their memorial to the state legislature of 1901-2 was received, was very discouraging, and would seem to indicate that the people of Michigan are not yet sufficiently informed of the value of such a survey to make it for the interest of their representatives to promote it.

It is gratifying, however, to know that a commencement of this work has been made, for which we are indebted almost entirely to the zealous efforts of our member, Mr. Alfred C. Lane. By devoting to this purpose a portion of the appropriation for the state geological survey for 1902-3 he was enabled to obtain the coöperation of the United States Geological Survey so far as to secure the survey of the quadrilateral enclosed between the parallels of longitude 83° 30′ and 84° west and of latitude 42° and 42° 30′ north, and including the cities of Ann Arbor and Ypsilanti, most of Washtenaw county, and portions of Livingston, Oakland, Wayne, Monroe, and Lenawee.

Mr. Lane also succeeded, with very effective assistance from the Michi-

gan Academy of Science in persuading the last legislature to appropriate the meager sum of $1,000 to be expended during the year ending June 30th, 1904-5, for the continuance of this work. It is hoped that by means of this appropriation, with the aid of the United States, the survey of another quadrilateral, including the city of Detroit will be accomplished. The map of the first quadrilateral has been completed, but has not yet been published. A very few moments' inspection of this map ought to be sufficient to convince any intelligent man of the immense value of this survey, not only to engineers, but to all persons owning property or interested in public works or industrial enterprises of any kind in the state. It is reported that by the use of a single sheet of the Topographical Survey of Ohio, the locating engineers of the Wabash railway were recently enabled to change their previous location so as to save 2,300 feet of distance, and a summit termed 800 feet long, at an estimated money value to the company of more than $70,000.00. If such an amount can be saved by a single sheet by a single enterprise, how much can we not fairly hope for from a complete survey of the state.

Possibly a copy of this completed sheet placed in the hands of each member of the legislature to be elected next fall, would be the most convincing argument that could be used to advance the object which we have in view.

It would be, perhaps, too much to hope that this legislature can be induced to make any large appropriation, or to enter upon any general plan of survey, but it is not impossible that the members of this society from those sections of the state which are most largely represented, such as Grand Rapids, Saginaw, Kalamazoo, Battle Creek, etc., could, by personal efforts with their representatives, induce them to combine to carry through an appropriation which would cover the survey of those sections, and thus carry on the good work which has been begun.

E. W. MUENSCHER,
Chairman.

Prof. E. E. Bogue of the Agricultural College wants a similar survey as soon as may be to cover the college area. It is in the line of work which the board can do with limited means but very slowly. To aid in the work the legislature of 1903 made an appropriation, which was cut down before passage to $500 per annum,—not even enough to make one-half of the smallest unit of mapping without supplement.

In the course of the summer I found out by expensive experience from the auditor general that having had an appropriation for a specific purpose, the general appropriation could not be used for that specific purpose, though the same object be covered by it, and the only way I could aid was by doing a certain part of the work entirely at our own expense.

But it caused me a good deal of anxiety of mind and I also had personally to carry something like a thousand dollars worth of expense for a month or two. I would therefore recommend that any further additions which the legislature may see fit to give to hasten the work of the topographic survey may be either in the shape of additions to the general fund, or in sums of not less than $2,500 per annum.

The schoolmaster's club, and teachers' association as well as the Academy of Science are showing more interest in the work of the survey as the equipment of the teachers improve. I am not inclined to urge the study of geology as such into the grades. Too much preliminary knowledge is required before beginning its scientific study. What is advisable

and useful can best be given in connection with a good physical geography. One can hardly describe the earth as it is, without some reference as to how it came to be so, especially when the agencies are still at work.

I would also urge that mineralogy is a very interesting subject, giving play to the collecting instinct, and of peculiar interest to many boys. In the boulders or hardheads scattered over our fields almost any mineral may occur. Practical experience shows that it tends to hold boys in school better than biology and I should recommend that mineralogy be allowed as an alternate to botany or biology, where the teacher desired and the local conditions made it advisable.

A committee of the teachers' association have prepared a handbook for the use of teachers. If possible it would be well to have this widely published and distributed among the teachers.

By an arrangement with the university, needed analyses have been made for the board under the direction of Prof. E. D. Campbell at half the usual rate, mainly by E. E. Ware and L. Kirschbraum. Many, such as those of the Lighthouse point quartz diabase, and those of a series of clays for Prof. Sherzer, are inserted in appropriate places.

A piece of fusible slag from our Michigan coal was sent me. Such slag occurs rarely but occasionally in connection with the Saginaw seam. It seemed to me worth while to have it analyzed to verify my suspicions that it was due to black band ore. The following is the result:—

Loss on ignition	.....
SiO_2	33.84
Al_2O_3	32.50
Fe_2O_3	5.68
FeO	13.80
CaO	22.60
MgO	1.64
	100.06

This was tested for ZnO but the chemist could find no appreciable trace of it.

In the notes turned in by W. M. Gregory for the gypsum report, Volume IX, Part 2, on the Alabaster region, there were some remarks on recent changes of the Lake Huron shore which seemed hardly pertinent to that report but were of such interest in themselves as to deserve insertion here.

RECENT SHORE FORMS.

BY W. M. GREGORY.

Outside of the glacial region and between the lake level and the Nipissing beach is a strip of land which is due entirely to recent lake formations, some of them within historic times. The general shore structures of the eastern edge of this area show the direction of the adjustment of the beach to the lake currents by the smooth curves, convex to the lake, present in the outline of the shore, both in the larger features and the smaller ones. The most interesting place where these recent formations

have been more rapidly built, is at Tawas point. This formation is spoken more of at length below. The places in the "bight" of Tawas Bay show how the building out of this point is gradually weakening the building effects of the waves on the shore in its shelter.

One of the familiar features along the shore are the sand dunes; in many places arranged by storm waves and wind action into lenticular dunes with the longer axes northeast and southwest. These are often cut later into several smaller ones by wind action, or perhaps the entire top blown off, forming a dune which resembles the crater of an old volcano.

The cutting of the lake shore is going on very extensively in regions which may be located as in general above prominent points. The erosion of the lake bank a mile and a half above Tawas point, has carried the bank inshore some 50 feet within the memory of the fishermen living there and as shown by recent surveys. Cutting has also taken place below Tawas City, and this is due to an eddy current which is traveling in the bay, and its effects have been very extensive. A large amount has been expended in building a revetment and otherwise lessening the erosive action of this current which is often aided by the northeastern storm waves. In this same region the Detroit & Mackinac R. R. once ran in front of the old Presbyterian church, but because of the extensive cutting, thus causing the caving of the bank, the track was moved a distance back of the church and at the present time where the track stood the bank has been cut out some five to ten feet, almost wholly through wind action. This has been done within the last 15 years. Very extensive cutting has also taken place in a long stretch of this shore from Harmon City down nearly to Point Lookout. In this region, the average height of the bank varies from 10 to 20 feet. All of the points below these regions of extensive cutting are building spits and are otherwise rapidly enlarging, thus showing where part of the material being removed is being placed.

FORMATION OF TAWAS POINT.

This has been spoken of as Ottawa Point, Tawas Point, or Whittemore Point, and is located some two miles directly east of Tawas City in Iosco county, and it is so excellent an example of the formation of "cuspate forelands" that it is deemed worthy of a rather careful consideration. It has long been known by the settlers of this region that the point has been in process of rapid building. The bay has always been one of excellent refuge for ships in the case of storms and a lighthouse has always been maintained for aiding navigation. The trouble with the location of these lighthouses has been that they were built on the end of the point and by its rapid growth needed to be moved from time to time not to be misleading. There have been two of these lighthouses and also a fog horn, built in recent times. This of course, has been due to the action of the currents in rapid building and similar phenomena have been discussed by different people in other regions, but this particular point, excellent as a type of formation of cuspate foreland, has been overlooked. It has been used by the writer as a practical exercise in geological excursions (field) in school work and has been a source of excellent results to the pupils who have lived in this vicinity.

A few notes may now be given pertaining to the building at this point. The first lighthouse which was located in this region was built in 1856. The light was located on the end of the point at that time and the water's

edge was only 15 feet away, and there was no land to the southeast. At this time there were several small ponds in back of the lighthouse. This was 1800 feet northeast of the present light, which was built in 1876. Thus in 20 years a stretch of land some 1200 feet in length and 1000 feet wide in average was added. This enables somewhat definite estimate of the power and the rapidity of the point building forces of this region.[1]

The building action is largely due to waves throwing up the sand and the wind blowing the sand out of the water and piling it up in dunes, thus slowly adding to the land already in place. The water coming down the shore is supplied with plenty of sand and what is not extracted from the waves by the winds is carried to the point where the waters of the lake meet the waters of the bay and at this dead water triangle between the two currents opposite in direction, it is utilized in prolonging the length of the point. These normal conditions are often disturbed by a change of wind which introduces changes of the currents.

The new lighthouse, as has already been stated, was built in 1876 and was entirely surrounded by water, being built on a firm area of land between which and the mainland there was a passageway from the bay to the lake through which fishing boats of large size often passed, and through which the surf boats of the life-saving crew were taken from the station to the bay to work in the lake. At the present time this passageway has been closed at the ends and is only a swamp between two high ridges of sand. The old shore lines on the point are marked by faint beaches of well worn brown, sandy, shelly pebbles. The surface of this point has been made over almost entirely by wind action where many forms of dunes are seen covered with very little vegetation. It is possible to see the dunes in the embryonic stage, its fullest development with a smooth full top, and in the stage when the top becomes blown off, which is characteristic of its old forms.

In addition to the lighthouses above mentioned, there was built in 1900, because of the point's rapid growth, a fog horn .6 of a mile southwest of the present lighthouse, being at the present end of the spit. The land between the fog horn and the lighthouse has a width of some 600 to 800 feet, spindling down to some 200 feet at the fog horn and turning off sharply to the northwest where it forms a hooked spit. The average height of the land between the present light and the end of the point is some three to five feet. On the lake side of this formation at the water's edge, are many small pebbles, well worn and making a distinct beach. Going lakeward these increase in size. Out 100 feet from the present shore line, there is a distinct bar or ridge formed, which is the predecessor of the point which is to come. On the off shore side of the point the water is very shallow in this region, being from one to four feet deep, out for a distance of more than three-fourths of a mile, where it drops off very suddenly to a depth of 15 feet. In the inside curve of this spit or as it is locally known, the "bight" of the bay, there is no distinct shore line as along the outer edge of the point. The sediments here are very fine silt, mud, bark and floating debris, and it is a place much loved by ducks, the mollusca and other fresh water shells. Here are many good examples of ripple marks, wave prints and the tracks of different animals. A large

[1]It is adding say 1,200 feet in 20 years, 3,168 feet in 24, say 60 feet a year, or in area 1,200 × 1,000 in 20 years or 3,168 × (700 to 200) in 24 years, or almost exactly 60,000 square feet a year. The area of the point proper from section 13 to section 21 is only about 1.6 square miles, projecting perhaps four miles from the normal coast contour, so that figuring by length it would only take some 350 years or by area 460 years to have produced the whole point.—Lane.

part of the bottom is exposed by the water when the level of the lake is lowered by reversed currents of water due to wind action.

The currents which cause the building have been carefully observed throughout a period of several years by the writer and some explanation of the facts may be attempted on the data attained. The currents are dependent upon the direction of the wind. The prevailing direction of the wind for one-fourth of a mile out from the life-saving station is to the southwest, but this direction is reversed during a heavy southwest wind. The general current has been shown to be as above stated by the drifting of boats, floatwood and a series of tests with bottles. The objects when placed in the lake from small fishing boats, located off the life-saving station, were found to take a course to the southwest which brought them to a point near Alabaster. In heavy storms from the northeast a very strong current runs down this shore and strikes the shore of Saginaw Bay at Harmon City and Alabaster. This was shown to be the case when the steamer Baltimore was wrecked above AuSable, which occurred in 1900. Some of the wreck material was thrown on the beach just below Alabaster and the course of the wrecked boat was in this direction, which the current takes during heavy northeast storms. At such times there is formed an eddy in Tawas Bay, this eddy current having a direction on the shore opposite to that of the lake, and thus where the eddy current and the lake current come together at the end of the point, there will be formed a dead water triangle, and in this triangle the addition to the land will take place. The prevailing direction of the currents are as indicated above and have been tested several times to prove the correctness of the theory. During the use of the dredge at Tawas City, the muddy water was carried in the direction of the eddy referred to, and W. O. Emery of the custom office has observed these currents for a number of years and believes that the eddy's general direction is to the northeast along the shore of the bay, while outside the point the prevailing current is to the southwest. In considering these currents in this discussion, we must remember that these directions can be reversed during a storm.

The ridges which are formed and which are the most prominent feature of the point, are believed to be the result of big storms. At Tawas beach there are as many as a dozen of these ridges nearly parallel with a decreasing elevation as they reach the water. The heaviest storm of the season builds the highest beach, and thus when the water stands at the same level there are a series of beaches commenced. The sharpness of these storm ridges which have been formed during the building of the point decreases as we pass up the bay under shelter of the point. The old ridges which are prominent and extend entirely across the point and are being cut by the lake waves at present, were built before the point was formed and resulted from the formation of a similar point before the present one, for if the present point were to build rapidly across the bay and close in a body of water, we should have exactly the conditions under which Tawas lake was formed and later Lake Solitude. Some of the members of the U. S. L. S. station have observed the formation of these storm ridges which have been built in a single night's storm to some 5 or 6 feet above the lake level.

The water of Tawas Bay varies in its level considerably, being dependent upon the direction of the wind and its strength. In November, 1901, the wind from the northeast raised the level of the water some three feet, according to the authority of Engineer Black of the East Tawas Water

Works, and on April 14, 1901, in four hours the level of Tawas Bay was lowered 1.64 feet by a southwest wind.

Lake Solitude, which is located on the "bight" of the bay, is a shallow lake with muck and silt in the bottom with a large sandy ridge nearly dividing it into two distinct parts, and with an elevation of 2.5 feet above Lake Huron. This lake had two outlets at one time, or more properly was connected with Lake Huron, being merely a passageway between two sand ridges. When the level of the lake fell the water was partly drained off, and because of the sand bars which choked the entrance, a considerable area of water was left behind forming a lake, which in time demanded an outlet, and this was accomplished by cutting across the places where the wave action was slight under the protection of the building spit, and thus making a small outlet to the lake, while the older became clogged by the action of the waves on the Lake Huron shore. This is a rapid sketch of the formation of many of the lakes along this shore.

Tawas lake, which lies to the northwest of these smaller lakes just described, has the same general characters, being nearly filled with silt, muck, and abundant growth of vegetation. It evidently was formed between the Algonquin and the Nipissing beaches, and was evidently the first point formed in this region by the action of the currents in building off the shore bars and spits, as its western border in many places rests on the eastern edge of the Alcona moraine.

From Au Sable all along the shore to Au Gres, the tendency of storm waves to build ridges has formed heavy ridges running parallel to the shore line, having between them swales and swamps, rendering the drainage very much obstructed, and in many places where the distance between the ridges is large, cranberry marshes have been formed. These large ridges in many places have been cut away and now the old cranberry marsh is being cut into by the waves. There are several places along the shore where this is shown and also places where the sand has been duned and carried in shore by the wind, exposing a section of the cranberry marsh at its base as the waves cut away.

The Tawas river and other rivers of this section have a tendency to build deltas where the force of the river currents is less than that of the lake currents. This has taken place at the mouth of Tawas river. The building takes place in the spring and fall. The current of the AuSable is much stronger than the prevailing lake currents and the sediments are carried some two miles down the shore where, according to Captain Small of the U. S. life-saving station, there is a large shallow area, some one-half mile off shore, and this is being converted into an island whose sediments are derived from the river. The Rifle river has built a large delta at its mouth, some five miles square in area, and the Au Gres river has a current which is so sluggish that the channel to Saginaw Bay is kept open with difficulty, and a long area of land in front of the river mouth is slowly forming the river delta.

PUBLICATIONS.

In publication this year has been signalized by the completion of Volume VIII of our reports, containing three papers bearing on the raw materials of cement. (We are still at work upon the limestones, concerning which many facts have been given in our annual reports.) This report has elicited such comments as this from Municipal Engineering (Aug. 1903, p. 121): "The most valuable work on the manufacture of cement from clay and limestone or marl which has yet appeared." See also the letter from Mr. Wentz. I also quote from the Indiana State Chemist:—

"Lafayette, Ind., Nov. 21, 1903.

. . . . . "Having had some experience in cement manufacturing in your state, it is evident to me that you have made a very broad and comprehensive treatment of the marl question and I wish to thank you very much for bringing Part III to my attention.

"Very sincerely yours,

"(Signed) CHAS. S. McGOVNEY."

Dept. of Geology, Drury College,
Springfield, Mo., Aug. 10, 1903.

Dear Sir.—I thank you for Volume VIII of the Michigan Geological Survey, and also for the annual reports for 1901 and 1902. They are of great value in my library, and I congratulate you on the character of the publications sent out by your Survey.

Very sincerely yours,
(Signed) EDWARD M. SHEPARD.

East Tawas, Mich., July 3, 1904.

. . . . . .

Gentlemen.—I have received the Geological Report of Michigan and am very much obliged for same. I find it a very valuable book and shall enjoy reading it.

Yours very truly,
(Signed) TEMPLE EMERY.

Union City, Mich., July 14, 1903.

. . . . . .

Dear Sir.—Please accept my thanks for Volume VIII of the Geological Survey of Michigan. The work contains just the information I was in search of.

Respectfully yours,
(Signed) E. G. ARDAGH,
Of the Peerless Portland Cement Co.

I have also issued as Part 1 of Vol. IX a paper which otherwise would have been included in the annual report, but was needed by the attorney

general's department as soon as possible, on the "Growth of the St. Clair Delta," by Leon J. Cole.

Part 2, of Volume IX, a report on the gypsum of the state by G. P. Grimsley will probably have appeared before this report is printed.

The expense is given in the financial statement below.

Our present system of distribution, which involves sending to none but college libraries and exchanges, except upon especial application, and to very few other than teachers outside the state except upon payment of a fair price, makes small editions sufficient. Possibly in some cases a more liberal distribution would be worth while as advertising the resources of the state more, and possibly in reaction against a too lavish distribution of public documents I may have been niggardly, but I do not think so. The press usually announces such publications, and those who do not care enough for them to write, will probably get along comfortably without them (and never know what they miss) and can better be reached by the periodical press. Large parts of our reports, at times practically the whole, are reprinted in magazines and technical periodicals, in particular the "Michigan Miner" and "The Gateway." I believe that your policy of extending the widest opportunities to editors who desire to use our material is a wise one.

PRINTING EXPENSES.

	Vol. VII.	Vol. VIII.	Annual, 1901.	Miscellaneous.	Total spent.	Total appropriation.
Sec. 2, Act 78, 1899:						
Prior to Jan. 1, 1902	$2,299 59	$626 84	.....	[1]$28 49		
Jan. 1, 1902-Jan. 1, 1903	.....	404 24	$637 25	[2]3 59		
		$1,031 06		$32 06	$4,000 00	$4,000 00
	Ann. 1903.					
Sec. 1, Act 231, 1901	$20 33	1,031 74	715 15	[3]118 50		
		$2,062 82	$1,352 40	$150 56	$1,949 17	$2,800 00
Sec 1, Act 178, 1903	90 00	Vol. IX.				
		Pt. I $257 78			$501 98	$1,250 00
		Pt. II 153 85		35		
		$411 63		$150 93		

[1] Covers and binding for reports 1899 and 1900 which were printed by Michigan Miner.
[2] Binding report 1902.
[3] $45.00 for maps of the State for separate distribution and the balance for illustrations of fossils.

The above is the financial statement of the expenditure of the annual appropriation. Money spent in conjunction with the U. S. Geological Survey in the topographic survey of the Ann Arbor sheet (you allotted $2,000), is included under field expenses. Salaries and office expenses are less than usual. This does not include the expenses for printing, which are given below. We have used up the appropriation of Act 78, session of 1899, for printing, and start on that of Act 231, session of 1901. The completion and binding of Volume VIII, which is now in press, and the printing of this report, if you so order, will use most of that.

1902–1903.

	Salary.	Field.[1]	Office.	Total.
July	$380.76	$396.67	$143.85	$921.28
August	279.47	38.90	104.21	422.58
September	273.67	554.11	37.55	865.33
October	355.24	71.13	156.33	584.70
November	312.00	78.39	46.56	436.95
December	344.31		45.02	389.33
January	313.80	56.67	12.52	382.89
February	428.17	49.78	76.75	410.70
March	311.53	6.18	61.91	379.62
April	274.00	242.93	91.01	607.94
May	[2]825.40	164.63	41.44	1,031.47
June	[2]1,133.75	178.72	69.97	1,382.44
Supplementary		171.60	5.00	176.60
Charged back unexpended				8.17
Total	$5,088.10	$1,909.61	$894.33	$8,000.00

[1] Including in part pay of temporary field assistants and payments on chemical work, etc., by contract.
[2] Including most of the salaries of assistants hired by the month or longer, and some payments on contract, e. g., $300.00 for gypsum report.
The above statement of expense follows the usual form. It is not always practicable to draw a consistent line between field expenses so far as temporary assistants are concerned, and salaries. The salaries of the permanent staff really amounted to about $300 00 per month.

I would call your attention to certain requests for new work which have come into this office, although it really seems to me we have all we can do for a year to finish work on hand and keep up with current explorations.

The American Institute of Mining Engineers, Mr. Merrill, one of the Smithsonian curators and others, are anxious that we should reprint the earlier reports. Inasmuch as they can no longer be obtained even from second hand book dealers, I think it would be wise so to do. The Academy of Science would like a natural science hand book for teachers published. The I. Stephens estate and the Upper Peninsula experiment station people are anxious for a map of the Upper Peninsula surface geology.

The Waverly Stone Co. and others would be glad to have a report on the building stones of the state like that recently issued by Wisconsin.

I cannot close this report without a reference of honor, respect, and regret to the departure from this life of Jacob Houghton, Esq., brother of Douglass Houghton, the first State Geologist of Michigan, who was, I believe, the last survivor of that survey. He also contributed to Volume II of the present series of reports, and to the end of a long life never lost interest in geology and faced camp life even when past the allotted three score years and ten.

Very respectfully,
(Signed) ALFRED C. LANE.

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